Analysis Of Three-Component Seismograms To Obtain The Result Of Moment Tensor Of Earthquake In Manokwari

I Setyowidodo\textsuperscript{1,a)}, B J Santosa\textsuperscript{2}, A D Handayani\textsuperscript{1}, S Widodo\textsuperscript{1}

\textsuperscript{1}Universitas Nusantara PGRI Kediri, Jl. K.H Ahmad Dahlan No.76, Kediri 64112, Indonesia
\textsuperscript{2}Institut Teknologi Sepuluh Nopember, Keputih, Sukolilo, Surabaya, 60111, Indonesia

\textsuperscript{a})E-mail: irwansetyo@unpkediri.ac.id

Abstract. This study analyzed three-component waveform inversion of the earthquake that occurred in Manokwari, Papua on January 13, 2010 at 17:18:11 GMT with a magnitude of 5.7 Mw which the epicenter was at -0.72 latitude, longitude 133.33 and depth of 42 km. The study used the local seismic data downloaded from the data of earthquake IA. Then, inversion of the seismic data were done by using iterative deconvolution methods. This method was implemented in ISOLA software which was developed to obtain the parameters of the epicentre. Furthermore, the results of parameters were used to determine the actual form of the fault by using the HC method. Synthetic seismograms were computed with ISOLA that the input was a model of the earth and the seismogram recorded by seismological stations MWP, SWI and LBM. Interpretation of the analysis of three-component seismogram waveform showed that the orientation of the field of earthquake fault in Manokwari, Papua on January 13, 2010 had a dip angle of 77° to the horizontal plane which caused the fault zone in the area which was easy to occur a shift and an earthquake. By this analysis, it was known that the cause of this earthquake faults were oblique strike-slip faults moving from the northwest to the southeast.

1. Introduction

Geologically, Indonesian archipelago is located at the confluence of two major seismic zones, namely the circum-Pacific belt and The Alpine belt. Because of its location, the Indonesian archipelago is in an area that has relatively high earthquake activity. Tectonic earthquake is shaking movement of the Earth which is caused by collisions among tectonic plates. Convection currents of the Earth’s core flow into the upper mantle. Those currents also control the movements of the plates. The continuance of continental plates’ impulse driven by convection currents in the upper mantle causes earthquakes and produces advanced deformations on the surface of continents [1].

Many studies have been developed to understand the structure and dynamics of the Earth as well as the mechanism of the earthquake through the parameter estimation of the epicentre CentroidMoment Tensor (CMT). CMT determination of the earthquake has been using single-component Green’s functions on the Z-axis only. Seismic waves move from the source to the observation station in three-dimensional space. Therefore, it is necessary to develop three-component Green’s function to estimate the earthquake source parameter carefully. This study compares station and synthetic waveform counted by using the Green’s function based on three-component waveform.
To understand the characteristics of this earthquake, it can be done by modelling the moment tensor of earthquakes [2]. The moment tensor model can be done by using inversion method with waveform [3]. Data analysis used in this study is local seismic data taken from seismic data IA (Internet Accelerograph). The results of this analysis are in the form of earthquake parameters which include scales, depth and energy of earthquakes as well as fault models causing earthquakes.

2. Theoretical Review

2.1. Moment Tensor

Seismic waves transmit elastic strain energy which comes out of earthquake’s seismic source. The velocity of seismic vibration is determined by the elastic modulus and the density of the material passed. Researchers who focus on terrestrial field conclude that the main cause of earthquakes originates from the force of movement in the Earth’s interior to push the crust, so that when the crust is not tough in responding to the force, it will create a fault and produce an earthquake. Model of fault motion and fault character of the earthquake cause can be recognized by the moment tensor of earthquakes. This moment tensor is used to describe the direction of the force which causes earthquakes [2]. Component of seismic recordings of a point source can be stated as follows:

\[ U_k(x, t) = \sum_{i=1}^{6} G_{ki}(x, x_s, t) * f_i(t) \]  

(1)

The concept of moment tensor can give a complete description of the force of seismic point source. Couples of the moment tensor component is described in the following figure 1.

![Figure 1. The force couples that make up the components of the moment tensor](image)

The nature of the moment tensor is symmetrical because \( M_{ij} = M_{ji} \). \( M_{ij} \) component value can be used to determine the parameters of the strike (\( \phi \)), dip (\( \delta \)) and rake (\( \lambda \)) causing earthquakes. Because \( M_{ij} = M_{ji} \), so there are 6 independent elements of the moment tensor left among 9 moment tensor [2]. The relationship among the moment tensor, a strike (\( \phi \)), dip (\( \delta \)) and rake (\( \lambda \)) is expressed in the following equation:

\[
\begin{align*}
M_{11} &= M_{zz} = -M_y (\sin \delta \cos \lambda \sin 2\phi + \sin 2\delta \cos \lambda \sin 2\phi) \\
M_{12} &= M_{yz} = M_x (\sin \delta \cos \lambda \cos 2\phi + 0.5 \sin 2\delta \cos \lambda \sin 2\phi) = M_{21} = M_{xz} \\
M_{13} &= M_{zx} = -M_y (\cos \delta \cos \lambda \cos \phi + \cos 2\delta \sin \lambda \sin \phi) = M_{31} = M_{zy} \\
M_{22} &= M_{yy} = M_y (\sin \delta \cos \lambda \sin 2\phi - \sin 2\delta \sin \lambda \cos 2\phi) \\
M_{23} &= M_{zy} = -M_x (\cos \delta \cos \lambda \sin \phi - \cos 2\delta \sin \lambda \cos \phi) = M_{32} = M_{yz} \\
M_{33} &= M_{zz} = -(M_{11} + M_{22}) = M_x (\sin 2\delta \sin \lambda)
\end{align*}
\]
The moment tensor can be used to measure earthquake strength by using seismic moment parameter (M0). Furthermore, variance reduction (Vr) and correlation (C) are calculated by equation:

\[ V_r = 1 - \left[ \frac{d - s}{d} \right]^2 \]
\[ C = \sqrt{V_r} \]  
\[ M_0 = \frac{1}{\sqrt{2}} \left[ \sum_{i,j} M_{ij}^2 \right]^{\frac{1}{2}} \]

in which: d = observation data; s = synthetic data

Weak zones are around fault ones. Hence, these zones are prone areas to get geological disasters, especially if the formed faults are still active or the areas are in the active tectonic zones, such as faults in Papua (Hannekam Fault Zone, Zaagkam Fault, Wanagon Fault Zone, Fault Meren Valley) that can cause catastrophic earthquakes [4].

![Figure 2. Focal spheres and their corresponding fault geometries [2]](image)

2.2. Geology of Papua

Papua is formed of the interaction of two plates, namely the Australian plate and the Pacific one. These elements are resulted from the compression force south-westwards to north-eastwards, in the direction of the collision. Papua is also formed because of a collision with an oblique angle between the Pacific Oceanic plate and Caroline plate moving southwards at velocity of around 110 mm - 125 mm/year.

The main crust involved in Papua is the Australian continental crust and Pacific oceanic one. The Australian continental crust is steady and becomes the foundation of the south while the Pacific oceanic crust is the base of northern coast, including Cendrawasih Bay. At that time, the tectonic processes in this area began to be encouraged so that it produced the position of collisions heading towards the southwest is more intensive. Very prominent parts of this tectonic are transform faults which go to the left, that is Sorong-Yapen fault zone [5].
3. Research Methods

The analysis method used in this study was three-component local waveform. The parameters of the earthquake source were estimated by using inversion model to achieve three-component fitting waveform properly. Good inversion was based on the results of matching of the observation data and synthetic data. Good results occurred if the observation data and synthetic data overlapped. Seismogram was recorded by network IA (Internet Accelerograph), then it was inverted by using Green’s functions which were calculated by the discretization method of number wave performed iteratively [6].

The data inversion process of three-component waveform used iterative deconvolution methods [7]. This method was implemented in ISOLA software developed to obtain earthquake source parameters [3]. The parameters of this earthquake were illustrated by using Centroid Moment Tensor (CMT). After that, the results of the parameters were used to know fault-plane by using H-C (hipocenter-centroid).

4. Data Analysis

The data used in this study are local seismic data taken from seismic data IA (Internet Accelerograph), namely earthquakes in Manokwari of Papua on January 13, 2010 at 17:18:11 GMT and with the hypocentre at -0.72 latitude, 133.33 longitudes at a depth of 42 km.

There are three selected stations because their locations are close to the source of the earthquake. Those stations are MWP, SWI, and LBM. The data analysis uses three-component waveform (BHN, BHE and BHZ). The parameters of the earthquake source are estimated by using inversion model to achieve proper fitting. This is based on the results of matching of the observation data and synthetic data in the inversion result which overlap each other. Comparison of the results of observation data and synthetic data as shown in the following figure 3.

![Waveform of Observation and Synthetic Data](image)

**Figure 3.** Waveform of Observation and Synthetic Data

Next, the interpretation is done on the Centroid Moment Tensor (CMT). This is a description of the fault model which causes earthquakes. CMT is described like beach ball which has a physical meaning that is, the bright part is the origin of the force pressing towards the dark region [2]. The CMT results of earthquake data processing in Manokwari Papua on January 13, 2010 showed that the kind of the earthquake was oblique strike-slip fault. The inversion results show that the earthquake magnitude is 5.7 Mw and the reduction variance is 0.70 with DC 54.50%, and 45.50% CLVD.
If the result of earthquake source parameter is compared with BMG data and USGS obtained from Emergency Response Team of the Center for Volcanology and Geological Hazard Mitigation, Geological Agency, and DESDM, it will be seen in the following table 1.

| Agency | Latitude | Longitude | Event          | Dept (km) | Magnitude |
|--------|----------|-----------|----------------|-----------|-----------|
| BMG    | -0.83    | 133.36    | 00:18:12 WIB   | 26        | 6.2 SR    |
| USGS   | -0.69    | 133.31    | 17:18:08 GMT   | 10        | 5.7 Mw    |
| Writer | -0.72    | 133.33    | 17:18:11 GMT   | 42        | 5.7 Mw    |

The depiction of fault-plane which causes earthquakes is performed by using hc-plot software based on the method of H-C [3]. Input entered on the hc-plot software appears as follows:

- Hipocenter: latitude = -0.69; longitude = 133.33; depth = 32
- Centoid: latitude = -0.72; longitude = 132.84; depth = 42
- Plane 1: strike = 210; dip = 60
- Plane 2: strike = 112; dip = 77

![Figure 4. Earthquake Moment Tensor](image4.png)

![Figure 5. Fault-Plane of CMT](image5.png)
Later, the result presents output centroid hypocenter = 10.64, the minimum distance from the field 1 = 7.19, and the minimum distance of the field 2 = 1.80, so that the depiction of the earthquake fault-plane in Manokwari Papua on January 13th, 2010 was earthquake cause faults are red. It means that these faults head towards the north-west – the south-east.

The earthquake on January 13th, 2010 occurred with magnitude 5.7 Mw whose epicenter was at latitude -0.72, longitude 133.33 and located at a depth of 42 km in the northwest of Manokwari. The area has high seismic intensity, especially with shallow depth of active fault systems. This is because it is close to subduction lane of Pacific oceanic plate and Australian continental crust in the northernward. As a result of the tectonic evolution, there are several active faults, they are Sorong Fault, Fault Ransiki, Aiduna Tarera Fault, and Jayawijaya Mountains Fault. In addition, the condition of quake-affected areas is generally composed of pre-tertiary metamorphic rocks, tertiary sedimentary rocks, and quarter sedimentary rocks. The pre-tertiary and tertiary rocks have experienced weathering and quarter rocks are generally loose, soft, unconsolidated and reinforcing effects of earthquake vibration so they are vulnerable to earthquake shaking [8]. Furthermore, the cause of the earthquake January 13th, 2010 is Sorong Active Fault system activity located in the northern part of Manokwari.

5. Conclusion

Based on the results of the analysis, it can be concluded that the earthquake occurred in Papua on January 13th, 2010 has a magnitude of 5.7 Mw. Epicenter is at -0.72 latitude, longitude 133.33 and a depth of 42 km in the northwest of Manokwari. The analysis also shows that the faults which cause earthquakes belongs to the oblique strike-slip faults that move north-westwards to south-eastwards.

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