Relocation of hypocenter using Jacobian's matrix and Jeffreys-Bullen's velocity model

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Abstract— Hypocenter is the center of earthquake that the position can be explained in x coordinate, y coordinate and z (depth). The location of the hypocenter is obtained by calculating the arrival time of wave propagation to station (at least three seismic stations) which is multiplied by the velocity model of the earth. To determination the position of hypocenter is used earth velocity model assuming a homogeneous of the earth. In reality the Earth containing in layers and the increasing of depth will make the material more compact, so it make the value of velocity wave propagates in each medium increase. It is necessary to recalculate the position of the hypocenter, so new position of hypocenter is accordance with the geological conditions. In this paper will use the study site on Java Island area with the amount of data are 19.685 events of tectonic earthquake. The processing using Matlab software with Jacobian's matrix calculation and using reference of Jeffreys-Bullen's velocity model. The results show that the relocation of the hypocenter position shifted relative to the southeast, while the depth become shallower.

Keywords— relocation, hypocenter, Jacobian's matrix, Jeffreys-Bullen's velocity

INTRODUCTION

The position of hypocenter is determined by the recording from a minimum of three receivers. The determination is using basic physics calculations based on the radius of the earthquake known by the arrival time of event and the velocity of wave propagation. Calculation would result the radius of the earthquake at each station (3 receivers) then the position of earthquake will be known by the intersection of its radius.

International Seismological Centre (ISC) is an institution that record arrival time of earthquake then report the position of the hypocenter. However, in the explanation ISC does not routinely use depth phases in their primary location of subcrustal earthquakes, and the ISC depth is the least reliable of their location parameters because don't know the depth of the hypocenter [1]. So many studies are relocating event on ISC data to get a new hypocenter position. Relocation is used to repositioning the hypocenter using a reference of velocity model at any depth. In this paper the relocation method used Jacobian's matrix based on Jeffreys-Bullen's velocity model to ISC data in Java.

THEORY

Jacobian's matrix used in this case is a matrix of three columns associated with the partial derivatives function of the travel time to the position of the hypocenter in x, y and z. Classified Jacobian's matrix is associated by the amount of data (N). The equation of Jacobian's matrix [2] is following:

$$J = \begin{bmatrix} \frac{\partial t_1}{\partial x_0} & \frac{\partial t_1}{\partial y_0} & \frac{\partial t_1}{\partial z_0} \\ \frac{\partial t_2}{\partial x_0} & \frac{\partial t_2}{\partial y_0} & \frac{\partial t_2}{\partial z_0} \\ \vdots & \vdots & \vdots \\ \frac{\partial t_N}{\partial x_0} & \frac{\partial t_N}{\partial y_0} & \frac{\partial t_N}{\partial z_0} \end{bmatrix} \quad (1)$$

Each component can be expressed explicitly:

$$\frac{\partial t_i}{\partial x_0} = \frac{(x_0 - x_i)}{v_p\sqrt{(x_0-x_i)^2-(y_0-y_i)^2-(z_0-z_i)^2}} \quad (2)$$

$$\frac{\partial t_i}{\partial y_0} = \frac{(y_0 - y_i)}{v_p\sqrt{(x_0-x_i)^2-(y_0-y_i)^2-(z_0-z_i)^2}} \quad (3)$$

$$\frac{\partial t_i}{\partial z_0} = \frac{(z_0 - z_i)}{v_p\sqrt{(x_0-x_i)^2-(y_0-y_i)^2-(z_0-z_i)^2}} \quad (4)$$

Convergence criteria is viewed by achievement of defined RMS error [2] as the average error which t_i^{obs} is the wave arrival time of observation and t_i is the wave arrival time calculation:

$$E_{RMS} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(t_i^{obs} - t_i)^2} \quad (5)$$

METHOD

The relocation process is using Matlab R2008b with Jacobian's matrix calculation and the reference of Jeffreys-Bullen's velocity model. Data used is tectonics earthquake data on the ISC website which is the earthquake in Java in 1900-2013. Comparison of the hypocenter position before and after relocation is shown in the 3D view using Petrel software.

Based on Fig. 1, the relocation process can be explained as follows:

- Input hypocenter position in the form of x, y coordinates, depth and travel time obtained from the origin time reduced by arrival time.
- Converting distance from geographic coordinates into UTM (unit kilometers) to the grid calculation. Further input grid size in x, y and z (dx, dy and dz to shift the position).
- Entering the value of velocity at any depth based on Jeffreys-Bullen's velocity model (Fig. 2).
- The calculation of relocation on the Matlab software using Jacobian's matrix (equation 1) in which each component of x, y and z are calculated by equation 2, 3 and 4. In this process we will get the value of ti (t calculation).
- Using the RMS error (equation 4) to determine the value of error from grid selection. If the error value is greater than 0 (> 0), need to determine the grid size again on point 2. If the error value is less than or equal to 0 (<0), determining the grid is appropriate.
- Save the relocation results as new hypocenter position that has been converted into geographic coordinates of reference. Done.

RESULTS AND DISCUSSION

The results are shown by Petrel software to compare the position of hypocenter before and after the relocation in horizontal and vertical. There are 19.685 events recorded by the 398 receivers (Fig. 3). It is data at depth of 0-800 km with an area about 500 km from the coastline of Java Island. In Fig. 3 shows that there are many of distribution data at depth of 0-300 km. Increasing depth, event disappeared at depth of 300-500 km, but the unique is a little of event reappeared at depth of 500 up to 800 km. This is shows from data recording that the tectonic movement is at depth of 0-300 km.

Grid used in relocation is 10 km at x coordinate, 5 km at y coordinate, while the z depth varies from 1, 2, 5, 10, 15 and 20 km getting as the increasing depth. Fig. 4 is the comparison between the hypocenter position before and after the relocation displayed from south. Yellow dots (●)

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indicate the position of the hypocenter before relocating while red dots (●) indicate the position of the hypocenter after relocation. Relocation results shown in red is indicating that the position of the earthquake became shallower and shifting toward the east.

Fig. 5 is the comparison between the hypocenter position before and after the relocation displayed from east. Relocation results shown in red is indicating that the position of the earthquake became shallower and shifting toward the southeast. Distribution of earthquake data reflect the subduction of the Indian-Australian Plate subducting under the Eurasian Plate. Indian-Australian Plate located in the south is moving to north since the Mesozoic and subducting under Sumatra and Java [3].

Fig. 6 is the comparison between the hypocenter position before and after the relocation displayed on the upper side. Subduction zone extends near depth of 670 km instead of 500 km [4]. Seen in the central part of Java Island were almost no seismic data in north-south direction called aseismic zone is reflect on the surface in the form of Central Java (right) and Citandui (left) Fault in the middle of Java Island [5].

CONCLUSION

Based on the results of relocation can be concluded that:

1. Relocation using Jacobian's matrix based on the reference of Jeffreys-Bullen's velocity model is shift the position of the hypocenter.
2. The hypocenter in horizontally is shifting toward southeast in 10 km at x and 5 km at y coordinate.
3. In vertically, it become shallower in depth of 1, 2, 5, 10, 15 to 20 km.

REFERENCES

[1] Adams, R. D., A. A. Hughes, and D. M. McGregor, 1982. Analysis procedures at the international seismological centre, Phys. Earth Planet. Inier., 30, 85-93

[2] Grandis, Hendra, 2009. Pengantar peomdelan inversi geofisika, Himpunan Ahli Geofisika Indonesia (HAGI), Jakarta

[3] Liu, C.S., Curray, J.R., McDonald, J.M., 1983. New constraints on the tectonic evolution of the eastern Indian Ocean. Earth Planetary Sci. Letters, 65, 331-342

[4] Schoffel, J. & Das, Shamita, 1999. Fine details of the Wadati-Benioff zone under Indonesia and its geodynamic implications, Journal of geophysical research, vol. 104, no. B6, ppp 13101-13114

[5] Setijadji, Lucas D., 2010. Segmented volcanic arc and its association with geothermal fields in Java Island, Indonesia, World Geothermal Congress: Indonesia