Earthquake effect on volcano and the geological structure in central java using tomography travel time method and relocation hypocenter by grid search method

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Abstract Relocating hypocenter is a way to improve the velocity model of the subsurface. One of the method is Grid Search. To perform the distribution of the velocity in subsurface by tomography method, it is used the result of relocating hypocenter to be a reference for subsurface analysis in volcanic and major structural patterns, such as in Central Java. The main data of this study is the earthquake data recorded from 1952 to 2012 with the P wave number is 9162, the number of events is 2426 were recorded by 30 stations located in the vicinity of Central Java. Grid search method has some advantages they are: it can relocate the hypocenter more accurate because this method is dividing space lattice model into blocks, and each grid block can only be occupied by one point hypocenter. Tomography technique is done by travel time data that has had relocated with inversion pseudo bending method. Grid search relocated method show that the hypocenter’s depth is shallower than before and the direction is to the south, the hypocenter distribution is modeled into the subduction zone between the continent of Eurasia with the Indo-Australian with an average angle of 14 °. The tomography results show the low velocity value is contained under volcanoes with value of -8% to -10%, then the pattern of the main fault structure in Central Java can be description by the results of tomography at high velocity that is from 8% to 10% with the direction is northwest and northeast-southwest.

1. Introduction
Java island has a lot of volcanoes and there are many earthquakes, it is caused by the subduction of the Indo-Australian continent with the Eurasian continent to the south of Java. The calculation of earthquake hypocenter position is often shifted from the actual position, this problem needs to be solved by relocating the hypocenter, in this research by Grid Search method. To determine the subsurface conditions it is done based on the travel time tomography method to know the velocity distribution in the subsurface that is useful to analyze the patterns of volcanoes and major geological structures in the province of Central Java.

2. Basic theory
Grid Search Method is a systematic search techniques. This method is one way to obtain a solution inversion nonlinear using a global approach by evaluating the value of an objective function on each model space in a systematic way, so it is necessary to get "a priori" information about minimum and maximum limits interval on each parameter models. Then the interval is discretized in order to obtain a grid that covers the entire space model, where the size of the grid is not always homogeneous.
The advantage of this method is the ease way of systematically evaluating the objective function for each sample on a room model that involves forward modelling, so non-linear problem solution can be resolved without linierization. But sometimes because of space models, this method becomes ineffective because of the many calculation of forward modelling, especially if the problem requires discretizing large scope. However, for a relatively simple matter with little number of parameters and small discretization, this method is efficient enough to be applied [1]

Seismic tomography

Tomography method is one way to describe the condition of the subsurface, which in this research has the purpose to describe the condition of P wave velocity in the subsurface based on some information, they are : velocity models used in reserach area, the P wave travel time from hupocenter to the station and the coordinate location of both of them. Because it uses the travel time data, then it is called delay time technique.

This method uses the travel time (travel time) along trajectory of the hypocenter as a source to the station as a receiver, with the following equation:

\[ T = \int_\text{penertaun} \frac{1}{V} dl \]  

(1)

Where dl is the length of the segment and V is the velocity of the medium [2]

Wave propagation is calculated for each segment. To simplified the equation discretization technique is used, so that equation (1) can be written in the form :

\[ P_i = \sum_{j=1}^{J} M_{ij} S_{ij} \]  

(2)

Where \( S_{ij} \) is the i wave length that crosses all segments j, \( M_{ij} \) is a function of the discrete model on the j segment where J is the total number of segments and \( P_i \) is the real data of the travel time.

Equation (2) can be solved by using inversion techniques, so that the equation (2) can be rewritten by:

\[ d = Gm \]  

(3)

Where \( d \) is real data, G is a forward modeling function and m is the model parameter to be searched, in this case the P wave velocity [3]

One way to obtain a solution of the parameters models are in the form of a matrix notation, where the solution by reducing the objective function of the model parameters, so the inversion technique to obtain the solution of the equation (3) can be written as follows:

\[ m = (G^T G)^{-1} G^T d \]  

(4)

\( G^T G \) matrix is a square matrix that is sized according to the number of model parameters  [1].

3. Data and method

This research use earthquake catalog data that recorded from 1952 to 2012 with a 9162 P waves number, 2783 S waves number, and 2426 event were recorded by 30 stations located around Central Java. Then the process of relocating the hypocenter and tomography performed with the parameters of the AK-135 velocity model.
Table 1. 3D Speed table AK-135

| Depth (Km) | Vp (Km/s) | Vs (Km/s) |
|------------|-----------|-----------|
| 0          | 1.45      | 0         |
| 3          | 1.45      | 0         |
| 3          | 1.65      | 1         |
| 3.3        | 1.65      | 1         |
| 3.3        | 5.8       | 3.2       |
| 10         | 5.8       | 3.2       |
| 10         | 6.8       | 3.9       |
| 18         | 6.8       | 3.9       |
| 18         | 8.0355    | 4.4839    |
| 43         | 8.0379    | 4.4856    |
| 80         | 8.04      | 4.48      |
| 80         | 8.045     | 4.49      |
| 120        | 8.0505    | 4.5       |
| 120        | 8.0505    | 4.5       |
| 165        | 8.175     | 4.509     |
| 210        | 8.3007    | 4.5184    |
| 210        | 8.3007    | 4.5184    |
| 260        | 8.4822    | 4.6094    |
| 310        | 8.665     | 4.6964    |

In Grid search method model space is defined as some lattice block, the smaller lattice block will generate more grid blocks to meet the model space. Lattice size of this block is done by trial and error but does not exceed the size of the model space. In this method we are using forward modeling assumptions (forward modeling) where we define the initial model for approaching the actual model. To find out the initial model with the actual model, it can be calculated by the following calculation.

\[ E = \sum_{i=1}^{N} (t_{i}^{cal} - t_{i}^{obs})^2 \quad (5) \]

To find out the error data obtained, the final result needs to be defined as the root mean square (ERMS) as follows:

\[ E_{RMS} = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (t_{i}^{cal} - t_{i}^{obs})^2} \quad (6) \]

4. Discussion
The results of the hypocenter relocation using Grid search Method:
The data processing is divided into 10 velocity layers model based on the table of AK135 velocity model, so that the process in the calculation of the relocation of the earthquake is divided into 10 stages based on the depth of each data.
The results of the hypocenter relocation using Grid search method indicates a significant change of position, when viewed from the east side corresponding figure 1 and figure 2, there is a change between the hypocenter before and after relocation. The hypocenter after relocation has a depth shallower than before, a change in position is very varied depths of 2 - 12.5 km in accordance with the grid being used. Then, when viewed from the east side most of the hypocenter after relocation moves towards the south.
The hypocenter distribution can also be interpreted as subduction, because tectonic earthquakes generally occur around the subduction zone. From Figure 3, the trendline of subduction difference before and after relocation, the subduction angle after relocation formed between the Indo-Australian plate with the Eurasian plate at 10.28 ° while the angle before relocation is 14.51 °. It is very useful to determine the age of the subduction. If the subduction angle is high then the plate subduction age older than the smaller angle of subduction. The subduction model after relocation can be seen in Figure 4.

The subduction zone model obtained from the hypocenter distribution, it is describe the location of the collision between the Eurasian continent with Indo-Australian continent, because in this area there are a lot of tectonic earthquake so that trendline hypocenter can be modeled by subduction model such as in Figure 5.
Results of Tomography Pseudobending

To perform a more detailed observations of the research area so vertically observed is needed by make two incisions in Slamet mount for the example. The incision in the form of A - A ' with longitude 106.503707 and latitude -6.751412 until latitude -7.650037 and longitude 111.697802 and then the incision B-B' with coordinates X = 109 205 and Y = -5.23 to X = 109 205 and Y = -9.23 . The incision A-A ' cut the mountain range on the island of Java, then the incision B-B' cut Gunung Slamet and perpendicular to mountain range of Java.

**Figure 6.** The incision tomography B-B' wave velocity P.

From the results of incision B-B' (Figure.6) there are anomalies below Slamet mount that has a very low P wave velocity that is -10% than the surrounding areas that has high velocity that with the range from -2% to 10%. If the P wave propagating in the fluid so the velocity will decrease, the P wave that propagates in the bottom of Mount Slamet has a very low speed, it is caused by the fluid form of magma below Mount Slamet, given the mountain of Mount Slamet is active. The depth of the low velocity anomaly below Mount Slamet started 3 km from the summit of Mount Slamet. Then the gray color of the incision showed there was no ray tracing passing through the area.

**Figure 7.** The incision tomography A-A ' wave velocity P.

In Figure 7 there are velocity difference between the eastern and western parts of the incision A-A ', this shows the difference of rock lithology between east and west, in the western part has a low velocity of -8% to -10%, while in the eastern part of the show ie value was -1% to -6%.

It adds to the confidence of previous studies (Reconstruction Tectonics microcontinent South Mountain East Java, [4]) that there microcontinent East Java who infiltrated the Sundaland, which indicated the velocity difference tomographic slice the A-A ', wherein microcontinent East Java has a higher velocity than Sundaland.
Figure 8. Map of the main structural patterns in Central Java with a tomographic method.

At a depth of 20 km it is clear that in complex fault structures large Cilacap - Pamanukan - Lematang and the complex structure of Kebumen - Muria - Meratus have the high velocity of 8% to 10%, this is because the alteration rocks process altrasi in the area of the fault. Faulting has pores large enough for the fluid that goes into these pores, at a depth of 20 km there is pressure and high temperature to allow for altrasi rocks in the fault complex. While low velocity found on the row of volcanoes and subduction-affected areas for rock bump so strongly that the rock reaches its melting point and becomes magma at the velocity of -8% to -10%.

5. Conclusion
1. Relocation Grid search method result show there are changes in the location of the hypocenter with the dominant direction of motion towards to the south and more shallow than the hypocenter before relocation with the change in direction of motion is 2 km - 12.5 km in accordance with the input grid is used.
2. Tomography result at the depth of 20 km show high velocity anomaly with a value of 8% to 10% contained in a large complex fault structures Cilacap - Pamanukan - Lematang and the complex structure of Kebumen - Muria - Meratus. While the region has a low anomaly with a value of -8% to -10% are mostly found in rows volcano in Central Java, then tomography in A-A 'shows the difference in characteristics between Central Java and East Java based tomographic velocity.

6. References
[1] Grandis, H. 2009. Pengantar Pemodelan Inversi Geofisika. ITB Bandung
[2] Nugraha, AD., Achmad S., Fatkhan. 2011. Jurnal Geofisika Edisi 2011 No.1
[3] Hidayatunnisa, S., Adi S., Muhajir A. ., Studi Tomografi Seismik Untuk Menentukan Model Kecepatan Gelombang P Daerah Bali
[4] Hussein, S. 2015, Tectonic Reconstruction microcontinent South Mountain East Java, Proceedings, National Seminar of Earth to-8, Department of Geological Engineering, UGM.