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# Swarm Earthquake Hypocenter Relocation in Ambarawa 22 October – 24 November 2021 using Double Difference Method

**Novita Sari Priyanto Putri[1]; Gatot Yuliyanto[2]; Udi Harmoko[3]**
[1-3] Physics Department, Diponegoro University, JL. Prof. Soedarto SH. Semarang, Indonesia, Postal Code: 50271
[2] gatoty@fisika.fsm.undip.ac.id

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***Abstract:** The swarm earthquake that occurred in Ambarawa from October 22 to November 24, 2021, was an earthquake with a relatively small magnitude and occurred repeatedly over a certain time span, which is commonly called an earthquake swarm. Disaster mitigation efforts needs to be carried out considering that the area most of the tourist destinations. To assist disaster mitigation efforts, it is necessary to relocate the hypocenter. The relocation of the hypocenter itself aims to obtain an earthquake hypocenter position that has a higher level of accuracy by taking into account the RMS (Root Mean Square) value. The data used in this study is data from the earthquake swarm that occurred in Ambarawa obtained from the Geophysics Station Class I Sleman, Yogyakarta. The method used to relocate in this study is the Double Difference Method using hypoDD software. The purpose of research is to obtain the hypocenter point of the earthquake which is the trigger for the earthquake as a form of disaster mitigation effort. The results is study are changes in the position of the earthquake hypocenter that form clusters in the area around the border of the Ambarawa subdistrict and Banyubiru subdistrict after the relocation. On average, a swarm earthquake occurs at a depth of 0 – 15 km below the surface with an average magnitude ≤ 3 SR and triggered by fault activity around Ambarawa.*

***Keywords:** hypoDD, Double Difference Method, Hypocenter Relocation, RMS, Swarm.*

## I. INTRODUCTION

Earthquake hypocenter relocation is one of the methods used to improve the accuracy of the hypocenter of an earthquake in an area. Earth's hypocenter relocation is carried out with the aim of determining a hypocenter point that has the potential to become a source of earthquake generators in the future.

Ambarawa itself is one of the sub-districts in Semarang Regency with the geological conditions of the Kaligetas Formation consisting of tuffaceous sandstone, lava flows, tuff, volcanic breccia, and claystone with a thickness of about 50 meters to 200 meters (7).

Earthquakes can be defined as events that occur due to the release of energy that has accumulated in the earth's crust towards the earth's surface (4). Earthquake swarms are earthquakes that occur sequentially without the main earthquake occurring.

Determining the hypocenter point can be done by relocating the swarm earthquake that occurred in Ambarawa and its surroundings. One method that can be used to relocate the swarm earthquake is the Double Difference method. The relocation of the Ambarawa earthquake swarm was carried out to add insight regarding hypocenter relocation and assist disaster mitigation efforts.

Earthquake swarms are earthquakes that occur sequentially without the main earthquake occurring. Swarm earthquakes themselves can occur within a period of weeks and produce so many earthquakes with relatively small magnitudes. Swarm earthquakes generally occur in volcanic areas, hydrothermal systems and active geothermal areas (3). Swarm earthquakes that occur due to tectonic activity basically occur due to active fault

 

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activity around the earthquake scene. This can be caused by creeping on the fault which results in de-aseismic or slow movement of the unlocked fault (6).

Earthquake hypocenter relocation can be defined as a method used to correct the position of the hypocenter so that it has increased accuracy by recalculating (1).

Earthquake hypocenter relocation can be done by recalculating the travel time between the earthquake source and the station. The earthquake hypocenter point after relocation can be obtained through computational calculations on earthquake models that have an earth structure that is similar to the original structure. This modeling can be obtained by minimizing the RMS (Root Mean Square). The RMS value itself can be obtained from the following equation (2):

$$RMS = \sqrt{\frac{e}{N}} = \sqrt{\frac{\sum_{i=1}^{N} r^2}{N}}$$

$e$ is the station correction , $N$ is the amount of data, $r$ is the difference between the measured and calculated travel times, and $i$ indicates the number of stations.

The Double Difference method or abbreviated as MDD is a method that utilizes the relatively small distance from the hypocenter of the two earthquakes when compared to the event distance to a station and the large scale of velocity heterogeneity, so that the ray paths obtained from the two earthquakes look similar. These two earthquakes can be said to have adjacent hypocenters, so they have similar waveforms and the difference in travel time between the two events observed at one station can be caused by the spatial distance between the two events accurately (5).

The Double Difference (DD) algorithm was first introduced by Waldhauser (2000) which aims to assist in determining the position of the earthquake hypocenter without having to model the velocity of the structure, so that the accuracy of the position of the earthquake hypocenter increases (8). The equation for the Double Difference method is obtained from the results of finding the difference in travel time in the Geiger equation which is used to determine the location of the hypocenter. An illustration of hypocenter relocation using the Double Difference method can be shown in **Fig. 1**. The equation for the Double Difference method can be written as follows:

$$dr_k^{ij} = (t_k^i - t_k^j)^{obs} - (t_k^i - t_k^j)^{cal}$$

$dr_k^{ij}$ is the residual value between the difference between the observed travel times and the calculated travel times for the two events, $(t_k^i - t_k^j)^{obs}$ is the difference in observed travel time between the two events, and $(t_k^i - t_k^j)^{cal}$is the difference in travel time calculation between the two events.

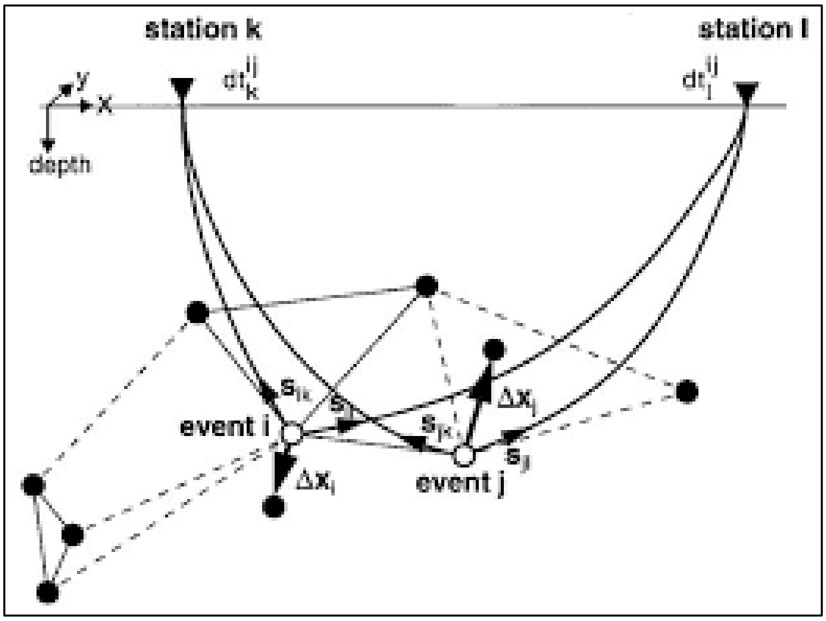


Fig. 1 Illustration of the Double Difference method

 

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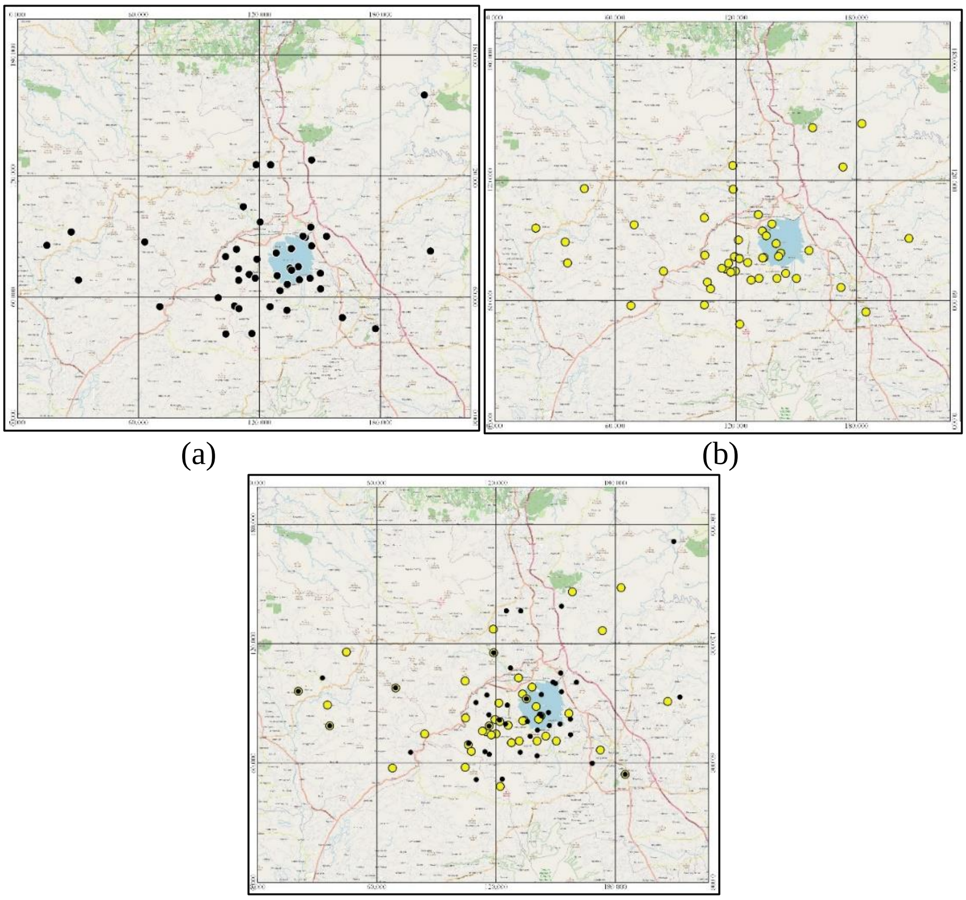
## II. METHODS

The research data used is earthquake swarm data that occurred in the Ambarawa area and its surroundings from 22 October to 24 November 2021 obtained from the Geophysics Station Class I Sleman, Yogyakarta. The tools used in this research are software, such as: Notepad++, Microsoft Excel, hypoDD, QGIS, Surfer, and WRPlot.

Data processing using the DD method is carried out by converting the data according to the input parameters that have been determined by the ph2dt program. Then parameter limits are determined, such as: MINWGHT (0), MAXDIST (500 km), MAXSEP (15 km), MAXNGH (20 events), MINLNK (4 events), MINOBS (4 stations), MAXOBS (100 stations). Furthermore, the running process is carried out on the ph2dt program and the resulting output is in the form of dt.ct and event.dat. The output is then copied to the hypoDD program and determines the parameters in the hypoDD.inp file before running again. After that, make a residual histogram of travel time, if the final result has an RMS value > 1, it is necessary to re-define the parameters and run the program again. However, if the RMS value is <1 and close to 0, then the relocation can be said to be successful and more accurate. Apart from that, it is also necessary to make a cross section and hypocenter rose diagram to find out the depth distribution points and the shifting direction of the earthquake hypocenter point.



(a) (b)

(c)

Fig. 2. (a) Map of the distribution of hypocenters before the Ambarawa swarm earthquake relocation; (b). Map of the distribution of hypocenters after the Ambarawa swarm earthquake relocation; (c). Map of the hypocenter distribution of the Ambarawa swarm earthquake before and after relocation

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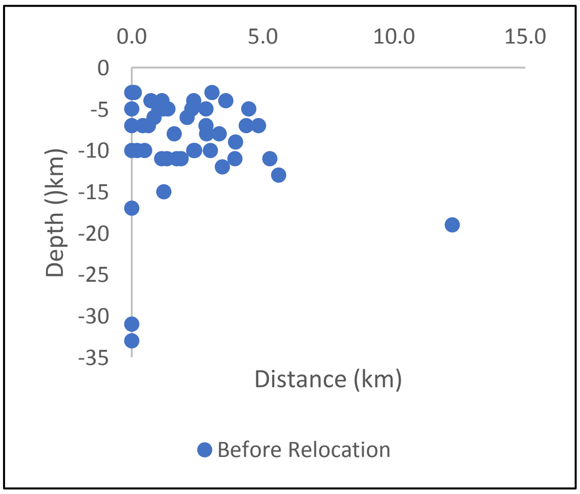
## III. RESULTS AND DISCUSSIONS

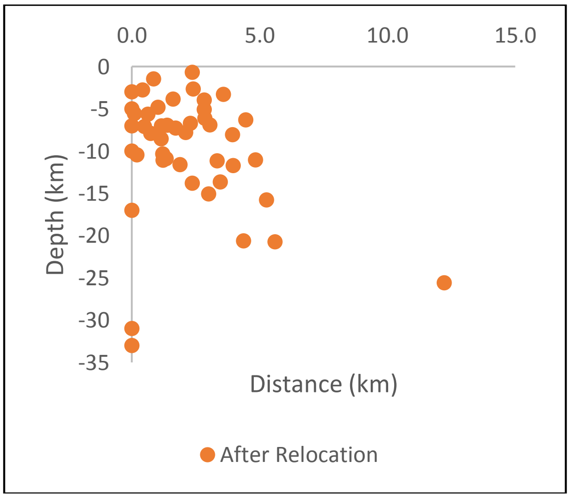
Based on the map of the distribution of the earthquake swarm hypocenter points in Ambarawa and its surroundings before the relocation in Fig. 2, as well as after the relocation, it can be seen that the earthquake hypocenter point has changed position. This can be seen from changes in values for latitude, longitude, and depth of each earthquake. The hypocenter point after the earthquake was relocated became more clustered to form one cluster, namely in the Banyubiru District area which borders Ambarawa District which can be seen in Fig. 2(b). For a shift in the hypocenter point from before relocation and after relocation it can be seen in Fig. 2(c) which shows that there was not a very significant shift. In addition, there are 7 hypocenter points that do not change position. This is because the point is located in the best and accurate position with very minimal error, while the other 38 points have shifted, although not significantly. This is because the hypocenter point before the relocation still has errors caused by external factors, such as the location of the earthquake recording station (high or low) which can be seen from its elevation and the speed contrast around the station. The hypocenter point cluster is located adjacent to the location of three active faults, namely the Merapi-Merbabu Fault, the Rawa Pening Fault, and the Ungaran Fault.

Cross section before, after, and comparison before and after relocation are given in Fig. 3. The distribution of epicenters before relocation which is indicated by blue dots which are scattered at a depth of 0 – 15 km below the surface (Fig. 3(a)), while Fig. 3(b) shows the distribution of epicenters after relocation which is shown by orange dots which are evenly distributed at a depth of 0 – 18 km below the surface. The average earthquake that occurs is categorized as a shallow earthquake because it occurs at a depth of <33 km. The difference in depth before and after the relocation of the earthquake can be seen clearly in Fig. 3(c).

The research area in Ambarawa and its surroundings can be said to be part of a subduction zone. This subduction zone is caused by the subduction of the Indo-Australian plate on the Eurasian plate. The subduction of the Indo-Australian plate on the Eurasian plate has resulted in the formation of regional geological structures in the form of faults along western to eastern Java which are the cause of tectonic earthquakes, such as the swarm earthquake that occurred in Ambarawa. These earthquakes occurred due to the activity of the three active faults, namely the Ungaran Fault, the Rawa Pening Fault, and the Merapi-Merbabu Fault. Fig. 4 shows the profile of the track area around the Telomoyo Mountain area and the result shows that there is no magma (volcanic) activity that can trigger an earthquake swarm. Based on the results of the analysis above, it is certain that the swarm earthquake that occurred in Ambarawa was caused by tectonic activity.



(a)



(b)

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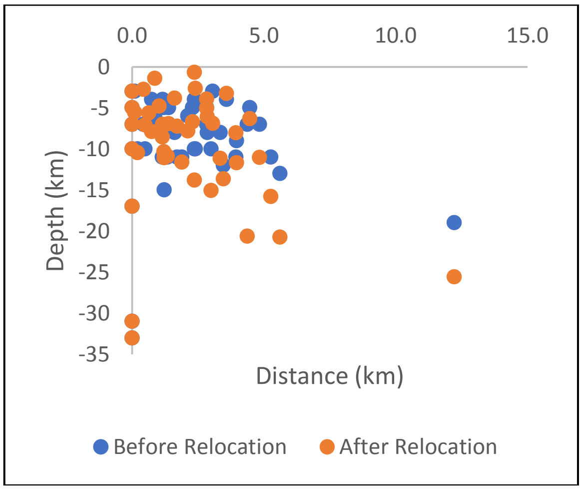


(c)

Fig. 3. (a) Cross section before relocation; (b) Cross section after relocation; (c). Cross section before and after relocation.

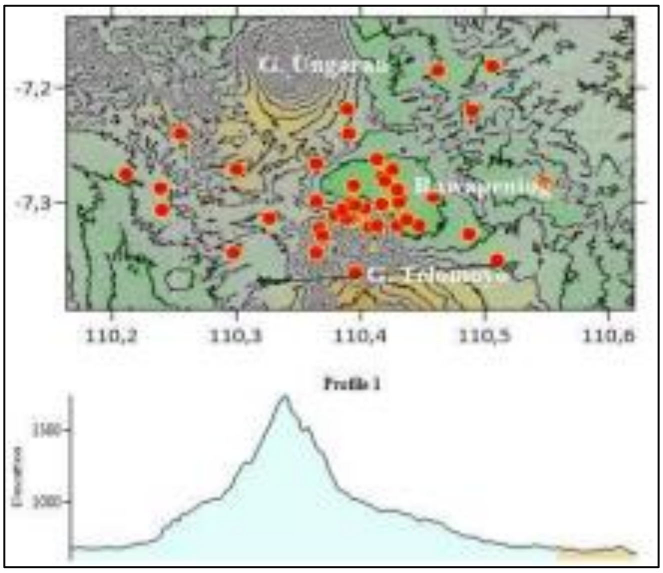


Fig. 4. Trajectory profile of the area where the Ambarawa swarm earthquake occurred

The RMS histogram before and after relocation are presented in Fig. 5. Fig. 5 (a) shows that before relocation, the residual values appear to spread with a range of -2 seconds to 2 seconds and collect at points -0.3 seconds to 0.5 seconds with the highest amount of data at points 0 seconds and 0.2 seconds with as many as 184. The RMS values appear to be spread almost evenly which indicates that the earthquake data before relocation had less than optimal accuracy. In Fig. 5(b), it can be seen that the RMS value after relocation appears to be conical and spread with a range of -1.3 seconds to 1.4 seconds and collects at points -0.1 seconds to 0.1 seconds with the highest amount of data at point 0.1 seconds with 362 data. These results indicate that relocating the hypocenter point using the Double Difference method helps in increasing the accuracy of the hypocenter position. This can be seen based on the RMS value which is close to 0, which is 0.1 and has a higher amount of data compared to before the relocation. The smaller the RMS value, it can be ascertained that the hypocenter point of the earthquake is getting closer to the actual earthquake conditions with the maximum level of validity.

 

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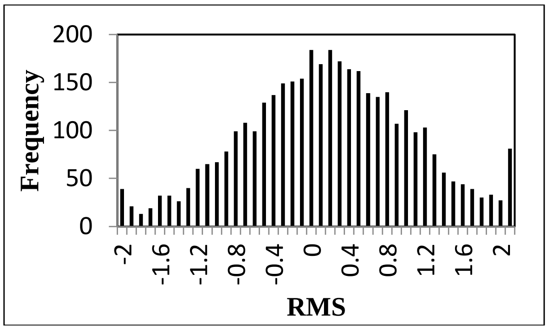
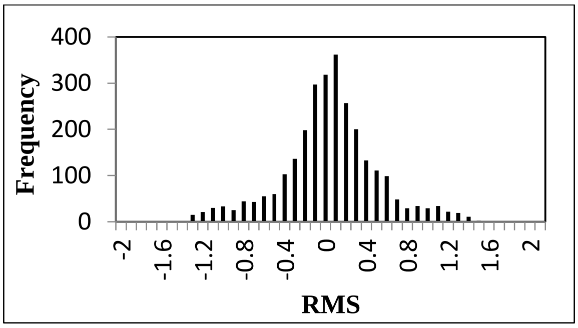



(a)




(b)

Fig. 5 (a) RMS histogram before relocation; (b) RMS histogram after relocation

## IV. CONCLUSION

Based on the results of research and processing of swarm earthquake relocation data that occurred in Ambarawa and its surroundings using the Double Difference method, it was concluded that there was a shift in the hypocenter point from before relocation and after relocation dominantly towards the north (18.1%) and west (14.5%) %) with the results of the RMS value using the Double Difference method having the highest RMS value at 0.1 seconds which is close to 0 with a total of 362 data. In addition, the relocation results obtained using the Double Difference method yielded hypocenter positions that were collected to form clusters in the area around the border between Ambarawa District and Banyubiru District due to tectonic activity in the form of fault movements around the earthquake site, namely the Merapi-Merbabu fault, the Rawa Pening, and the Ungaran fault and the geological conditions of the Ambarawa area and its surroundings.

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