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EARTHQUAKE RELOCATION USING THE DOUBLE DIFFERENCE METHOD IN THE BANTEN AREA CASE STUDY

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ABSTRACT
Banten Province is part of a konvergent movement between the Indo-Australian Oceanic Plate and the Eurasian (Europe-Asia) continental plate. The Indo-Australian Ocean Plate is moving north and colliding with the Eurasian Continental Plate. The earthquake on January 14, 2022 in Banten with a magnitude of 5.7 and a depth of 72 km was identified as a subduction lineation earthquake. Earthquake relocation is required to obtain accurate hypocenter results for tectonic conditions analysis. The hypocenter relocation method used in this study is the double difference method, which takes into account the travel time of the earthquake pair to the station. To obtain the best relocation results, the damping value test and several velocity models are also used. The best results were obtained. The best results were obtained using the MAXDIST 300, MAXSEP 50, and damping 25 parameters with the AK-135 speed model.

INTRODUCTION

Earthquakes are a natural phenomenon caused by tectonic plate movement, which causes a sudden release of energy, causing the ground surface to vibrate (Pawirodikromo, 2012). Because Indonesia is located at the confluence of three large plates, namely the Eurasian, Indo-Australian, and Pacific plates, earthquakes are common. The megathrust is formed when the Indo-Australian Plate subducts beneath the Eurasian Plate. It runs west of Sumatra Island, through the southern part of Java Island, and into Nusa Tenggara. As a result, tectonic earthquakes caused by subducting plate movements will occur frequently along this route (Hamzah et al, 2000).

Pandeglang Regency is located on Java Island's southern coast, close to the megathrust subduction zone. Earthquakes in the Pandeglang Regency area may also occur as a result of volcanic eruptions in the Sunda Strait, specifically Mount Krakatau, which has the potential to cause earthquakes and tsunamis (Wahyudin, 2011). The earthquake struck the Banten region on January 14, 2022, at 16.05.41 WIB, 132 kilometers southwest of Pandeglang City, Banten, with a magnitude of 6.6 on the Richter Scale (SR) and a depth of 40 kilometers. Banten province is located between 105º1'11" and 106º7'12" East and 5º7'50" and 7º1'1" South Latitude.

Accuracy in determining the hypocenter of an earthquake is critical when studying seismic activity and tectonic patterns in a region. As a result, accurate and consistent earthquake hypocenter locations are required in earthquake relocation. The double difference method is a popular method for earthquake relocation. This method has the advantage of being able to calculate a large amount of earthquake data at the same time. This method, which also pairs earthquakes, can take advantage of the difference in travel time as a function of distance between the two hypocenters (Waldhauser & Ellsworth, 2000).

The use of the Double Difference method to relocate earthquakes to the Banten region is expected to result in a more accurate hypocenter location. It is hoped that the results of this relocation will reveal the distribution of earthquake source locations and link them to the tectonic pattern in the area.

DATA AND METHODS

DATA

One of the data sources used in this study is the BMKG's earthquake catalog. The catalog contains earthquake parameters such as the date and time of the earthquake, latitude and longitude coordinates, depth, and magnitude. One earthquake catalog, the Banten earthquake catalog, is used (14 January 2022). The main shock of the Banten earthquake occurred on January 14, 2022. 71 events were successfully recorded using the earthquake catalog for the area boundaries of -5˚ to (-9˚) South Latitude and 103˚ to 107˚ East Longitude from December 1, 2021, to February 28, 2022.

A 1-D velocity model is also required for the hypocenter relocation process. This time, the AK135 speed model is used in the research (Kennett, E.R, & R, 1995) (**Figure 1**). This velocity model is also required in the Double Difference method algorithm to relate the difference in travel time for each pair of earthquakes with the function of the distance between the hypocenters of the earthquake pairs. The ak135 speed model used in this study is for a depth of 0 - 120 km and has six layers. This velocity model's depth range was also chosen based on the depth distribution of the relocated earthquakes.

Figure 1. AK-135F speed model.

METHODS

The data processing stage consists of several processes, namely determining the earthquake pair and the earthquake relocation process. The process of determining the earthquake pair is carried out by the hypoDD software's sub-program. In this process, several parameters are determined that are needed to determine the earthquake pairs that will be used in the earthquake relocation process based on the Double Difference method (**Figure 2**).

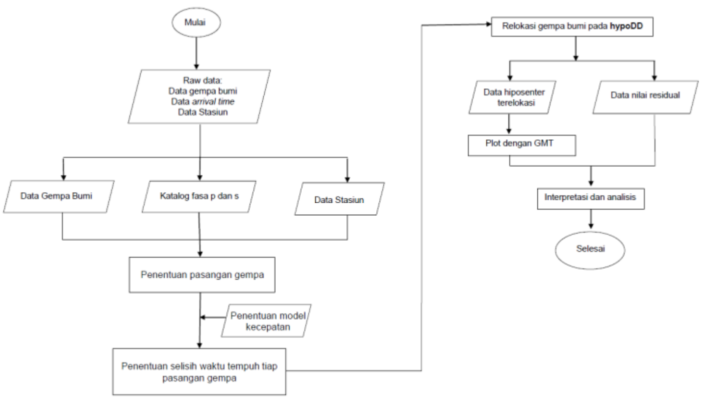

Figure 2. Research workflow.

The maximum distance between the station and the hypocenter (MAXDIST), the maximum distance between hypocenters (MAXSEP), the maximum number of each event (MAXNGH), the minimum number of neighbor relationships that can be paired (MINLNK), and the number of minimum and maximum observations that can be made are the parameters for determining earthquake pairs (MINOBS and MAXOBS).

In this study, MAXDIST parameter values of 300 km and 600 km, as well as MAXSEP parameter values of 50 km and 100 km, were tested to determine the best MAXDIST and MAXSEP parameters for further processing. The MAXNGH parameter is set to 10, as recommended by Waldhauser's hypoDD manual, and the MINLINK parameter is set to 1, indicating that at least one event can be related to another event. The MINOBS and MAXOBS parameters are set to 1 and 36, respectively, to represent the minimum and maximum number of stations capable of detecting earthquakes (**Figure 3**).

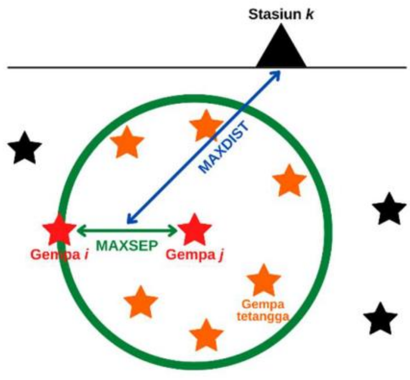

Figure 3. Illustration of the parameters used

This process will generate separate files containing earthquake hypocenter data and earthquake pair data. There is also data on the number of phases and earthquake pairs obtained for further analysis. In this process, it is also known that the number of phases and stations before use will vary depending on the parameters used to determine the earthquake pair. If there are phases that cannot be paired or stations that do not show an earthquake, these phases and stations are considered unable to meet the parameters that have been set. chosen. In this study, seven of the 36 stations can identify earthquake pairs.

Weighting and damping are used in the inversion process. The weighting values used are those commonly used by the Meteorology, Climatology, and Geophysics Agency (BMKG). While damping is used to dampen too large or unstable changes in the hypocenter, with a range of values used between 1-100 taking into account the Condition Number (CND) or ratio of the largest and smallest agent values obtained ranging from 40-80. (Waldhauser, 2001). A damping test was also performed in this study to determine which speed model produced the best results by taking into account the limit value of the Condition Number (CND).

RESULTS AND DISCUSSION

Analysis of the use of MAXDIST and MAXSEP Parameters

The analysis of several parameters used in the process of hypocenter relocation is carried out using a test of several parameter values to obtain one parameter that is most suitable for use in subsequent processing. The MAXDIST parameter, MAXSEP, is the value tested. The AK-135 speed model is used as a sample of the speed model used in this test.

The MAXDIST parameter specifies the greatest distance between the station and the earthquake hypocenter. This parameter is affected by the distribution of events as well as the number of stations owned. The improvement of hypocenter relocation results in significant changes, particularly at shallow depths, because most hypocenters were previously located at a depth of 10 km due to provisions of the depth of depth (fixed depth) of 10 km in earthquakes with less than or equal to 10 kilometers. MAXDIST 300 km has a lower value than MAXDIST 600 km in the average residual RMS value or residual histogram. The residual histogram serves as a validation of the hypocenter relocation results; as the residual value approaches zero, the calculation results obtained are closer to the real condition, indicating that 300 km is the most suitable MAXDIST for use.

The MAXSEP parameter value test comes next. This is the maximum distance between the hypocenter and the parameter. The MAXDIST parameter of 50 km was chosen for this test, and the AK-135 speed model was used as a sample of the speed model (**Figure 4**). The MAXSEP value is determined by the distribution of events, which generally has a value greater than 10 km based on the analysis of the distribution of local/regional events or up to the Teleseismic NI. ALI MAXSEP is the distance between the hypocenters of two earthquakes. In research, the MAXSEP value is 50 km.

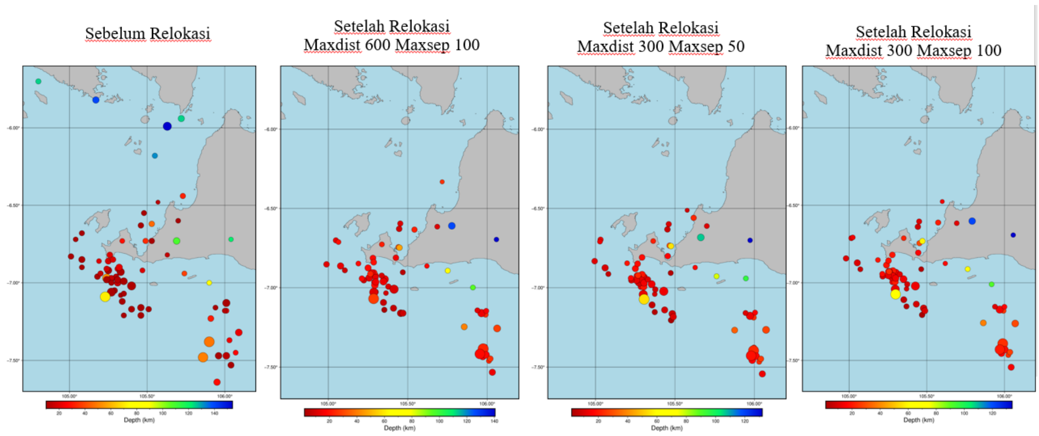

Figure 4. Comparison of MAXDIST and MAXSEP parameters.

To determine whether the relocation results are close to the actual condition, the distribution of the hypocenter before and after relocation must be compared. Figure 3.1 shows that the earthquake before the relocation is mostly at a depth of 10 km, with some at a depth of 11-154 km. This is due to the algorithm used by BMKG to determine the hypocenter, which results in a depth determination or fixed depth for earthquakes with a depth of less than or equal to 10 km. The depth of the earthquake was varied after the relocation, ranging from 3-154 km.

The distribution of the earthquake hypocenter after relocation is shown as a cross section on the A - A' path. Cross Section A - A ' was chosen due to the spread of the earthquake seen along the path with a shallow and varied depth (**Figure 5**).

Cross section B - B was chosen due to the distribution of earthquakes in the mainshock fence (**Figure 6**).

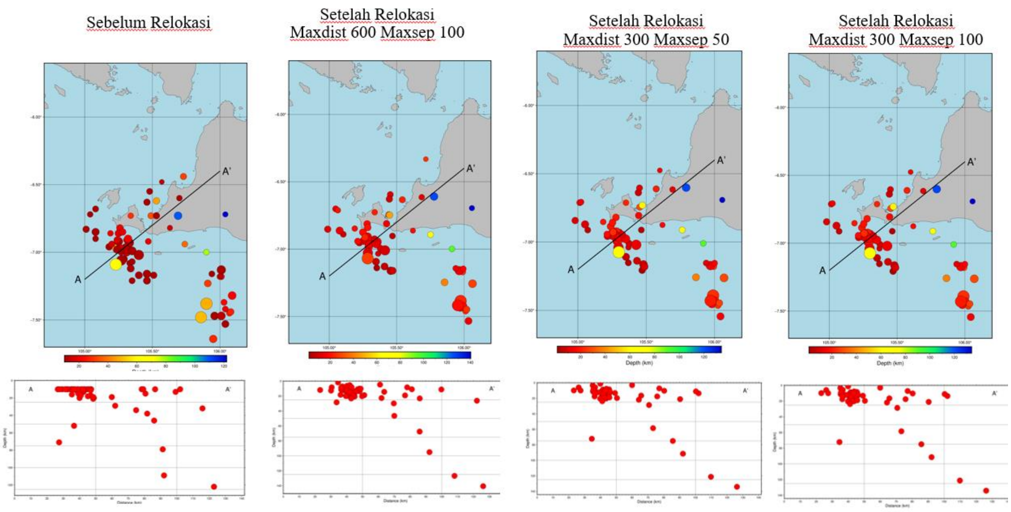

Figure 5. Comparison of cross section A – A' from MAXDIST and MAXSEP parameters.

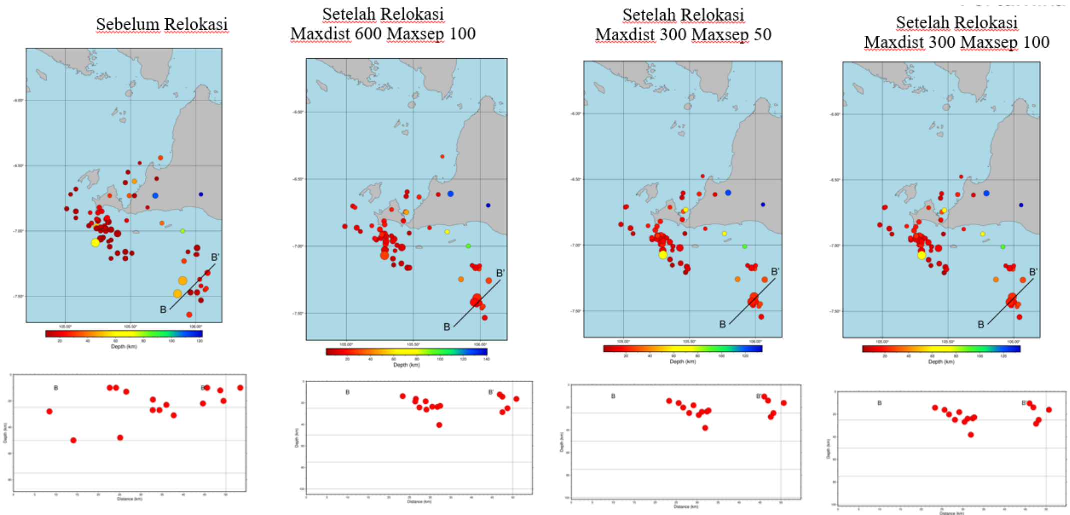

Figure 6. Comparison of cross section B – B' from MAXDIST and MAXSEP parameters.

There is no visible line of the subduction zone in Cross Sections A - A' and B - B'. This can be classified as an instrurab earthquake. In general, earthquakes in Instralab are caused by the presence of oceanic plates, which cause the plates to break or crack. As a result, the earthquake after relocation, as seen in Cross Sections A-A and B-B, does not follow a predictable or random pattern. When MAXDIST and MAXSEP are used, different residual average values are produced (**Figure 7**); this average residual value is used as a valid value for the selection of MAXDIST and MAXSEP parameters, which are considered zero as a parameter that describes the most.

The smallest residual value (0.00154) can be obtained after the relocation using MAXDIST 300 and MAXSEP 50 (**Table 1**).

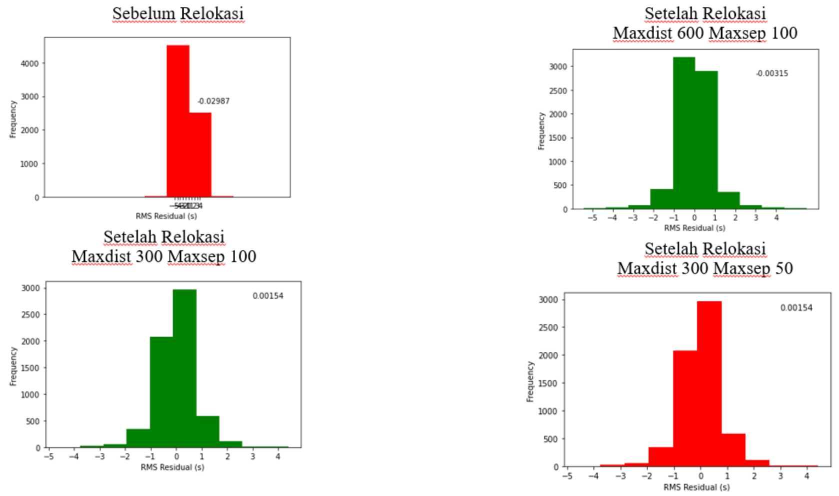

Figure 7. Residual histogram comparison of MAXDIST and MAXSEP parameters.

Table 1. Residual values of MAXDIST and MAXSEP.

	Residual values
Before Relocation	-0.02987
After relocation using maxdist 600 and maxsep 100	-0.00315
After relocation using maxdist 300 and maxsep 50	0.00154

Analysis of The Use of Damping Parameters

After determining the most appropriate Maxdist and Maxsep parameter values, the value is used with the AK-135 speed model as the speed model to calculate damping. Damping is the value used to reduce changes in the hypocenter that are too large or unstable, with a value range of 1-100 used so that a Conditional Number (CND) of 40-80 can be obtained. This damping must be determined for each speed model to be used. A damping value that is too large will result in overdamp or excessive damping, whereas a damping value that is too small will result in under-damp or hypocenter changes that are too large or unstable to be uncut.

The distribution of the earthquake hypocenter after damp parameter relocation is shown as a cross-section on the A - A' path. Cross Section A - A' was chosen due to the earthquake's spread along the path with a shallow and varied depth (**Figure 8**).

The values 20, 25, and 30 are used in this accompanying test, and the results are shown in **Table 2**. When damping value 30 is used, the average CND is small compared to damping values 20 and 25. This demonstrates that the damping value of 30 is too small to be used in the process of hypocenter relocation with indications of underdamping. In addition to the damping value, 20 produces a high average CND and can cause overdamping. As a result, the damping value of 25 is used, with the average CND value remaining between 40 and 80.

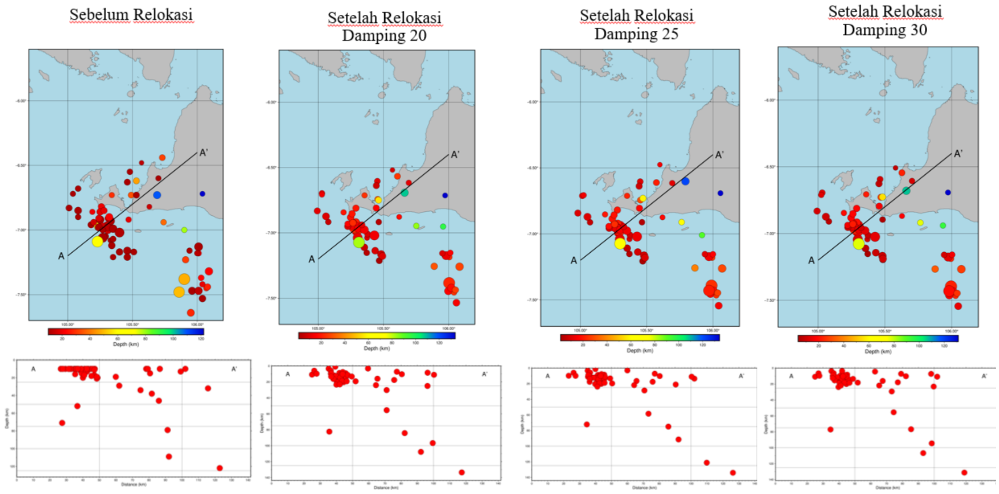

Figure 8. Comparison of damping in cross section with MAXDIST 300 and MAXSEP 50 parameters.

Table 2. Average CND and damping.

Damping	Average CND
20	70.78
25	54.25
30	42.75

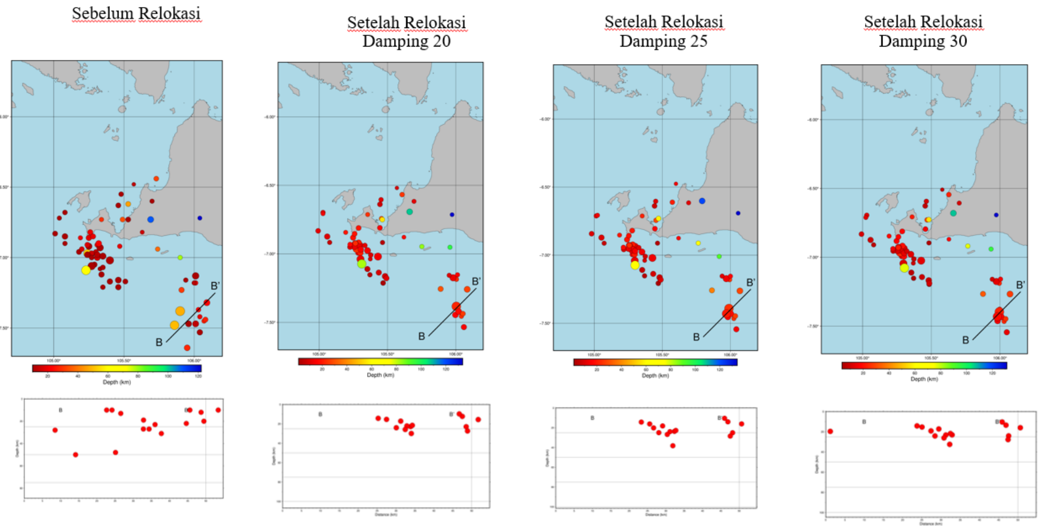

Figure 9. Comparison of Damping in Cross Section with MAXDIST 300 and MAXSEP 50 Parameters.

The damping value produces a different average residual value, which is used as a valid value for the selection of damp parameters, where a value close to zero is considered a parameter that describes the actual condition (**Figure 10**).

The hypocenter relocation was processed using a hypodd, which resulted in a residual value for each earthquake pair recorded by the station. **Table 3** shows the average residual and second for damping values of 20, 25, and 30.

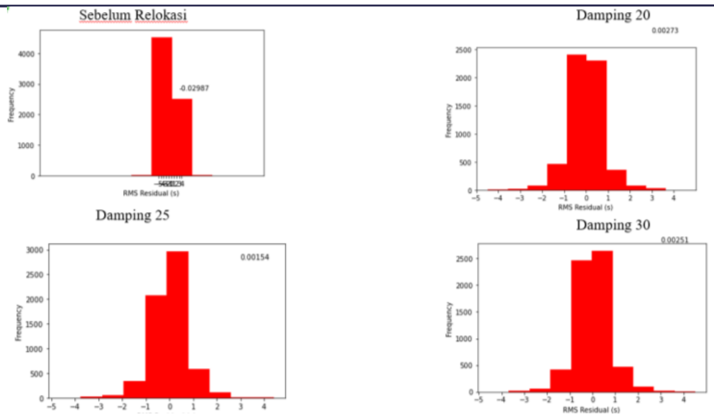

Figure 10. Residual histogram comparison of damping parameters.

Table 3. Average residual in damping.

Damping	Residual Values
Before relocation	-0.02987
After relocation using damping 20	0.00273
After relocation using damping 25	0.00154
After relocation using damping 30	0.00251

Based on the results obtained, a good residual value is processed using damping 25, where the value increases when compared to before the relocation and approaches zero, indicating that the results of the relocation obtained are getting closer to the actual situation.

The Compass and Rose diagrams are also used for the Banten earthquake to see changes in the location of the hypocenter in general. According to the Compass Diagram, the greatest shift distance is 25 km, with the majority of it shifted by 0 - 10 km to the East-Northeast direction (**Figure 11**).

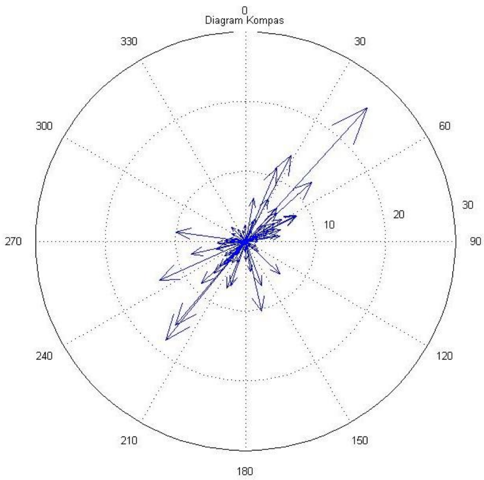

Figure 11. Result of the relocation of the Banten earthquake compass diagram.

Meanwhile, the Rose Diagram shows that the majority of hypocenter movement occurs to the East-Northeast, or a change in its dominant direction occurs around 7,888 km ().

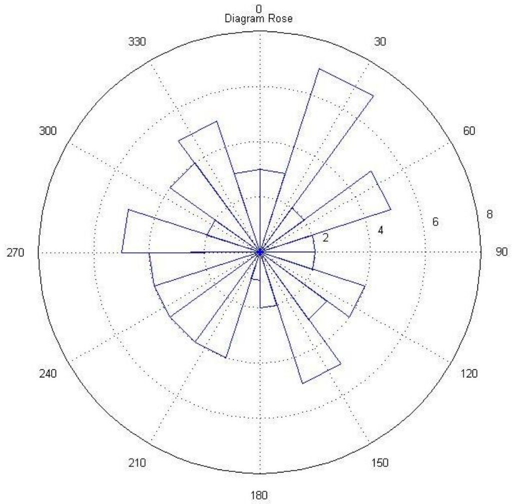

Figure 12. Result of the relocation of the Banten earthquake rose diagram.

CONCLUSION

The test results for various MAXDIST, MAXSEP, and damping parameters show that the MAXDIST 300 km, MAXSEP 50 km, and damping 25 values used in the hypocenter relocation process use the AK-135 speed model, which produces the best results, thereby improving the quality of the hypocenter relocation results.

The hypocenter relocation results can improve the hypocenter location of the earthquake distribution before relocation using the 10 km fix depth, particularly at shallow depths. Based on the processing, there is a change in the fixed depth of the earthquake, as well as a lineation of subduction in cross sections A - A'.

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REFERENCES

Afnimar. (2011). *Seismologi,*Bandung: Penerbit ITB.

Dziewonski, a. M., & Anderson, D. L. (1981). Preliminary Reference Earth Model. *Phys. Earth Plan. Int. 25,* 297-356.

ESDM, (2022). *Laporan Singkat dan Rekomendasi Teknis Gempa bumi Tanggal 14 Januari 2022.* Retrieved from Kementrian Energi dan Sumber Daya Mineral: https://vsi.esdm.go.id/index.php/gempabumi-a-tsunami/laporan-singkat-dan-rekomendasi-teknis/3909-laporan-singkat-dan-rekomendasi-teknis-gempa-bumi-tanggal-14-januari-2022#:~:text=Berdasarkan%20data%20lokasi%20pusat%20gempa,menyusup%20ke%20bawah%20Lempeng%20Eurasia.

Fremont, M., & Malone, S. (1987). High Precision Relatives Locations of at Mount St. Helens, Washington. *Journal of Geophysics Research, 92*, 10223-10236.

Hall, R. (2012). Late Jurassic–Cenozoic Reconstructions of The Indonesian Region and The Indian Ocean. Tectonophysics, 570-571, 1-41.

Hall, R., Cottam, M. A., & Wilson, M. E. (2011). The SE Asian Gateway: History and Tectonics of The Australia-Asia Collision. Geological Society, London, Special Publications, 355, 1-6.

Hamilton, W. (1979). Tectonics of the Indonesian Region. U.S. Geological Survey Professional Paper, 1078.

Havskov, J., Bormann, P., & Schweitzer, J. (2012). Seismic source location. New Manual of Seismological Observatory Practice 2 (NMSOP-2), 1-36.

Madrinovella, Iktri. 2010. *Relokasi Hiposenter Gempa Padang 30 September 2009 Menggunakan HypoDD.* Bandung : ITB Bandung.

Reynolds, J. M. (1997). An Introduction to Applied and Environmental Geophysics. West Sussex: John Wiley & Sons Ltd.

Setiyono, U., Gunawan, I., Priyobudi, Yatimantoro, T., Imananta, R. T., Ramdhan, M., . . . Kriswinarso, T. (2019). Katalog Gempabumi Signifikan dan Merusak 1821-2018. Jakarta: Badan Meteorologi Klimatologi dan Geofisika.

Sunarjo, Gunawan, M. T., & Pribadi, S. (2012). *Gempa Bumi Indonesia Edisi Populer.* Jakarta: BMKG.

Sunaryo et al. (2019). Distribution of seismic wave velocity. *AIP Conference Proceedings 2169, 050001 (2019)* (pp. 1-14). AIP Publishing.

Waldhauser, F. (2001). hypoDD -- A Program to Compute Double-Difference Hypocenter Locations. California: U.S. Geological Survey.

Waldhauser, F., & Ellsworth, W. (2000). A Double-Difference Earthquake Location Algorithm : Method and Application to The Northern Hayward Fault, California. *Bulletin of The Seismological Society of America, 90*, 1353-1368.