SUMEDANG EARTHQUAKE RELOCATION PERIOD DECEMBER 31, 2023 – JANUARY 4, 2024 USING *DOUBLE DIFFERENCE* METHOD

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ABSTRACT

On December 31, 2023, an earthquake occurred in Sumedang with a magnitude of M=4.8. The location of the epicenter is at coordinates 6.85'S and 107.94'E, or precisely on land at a distance of 2 km northeast of the center of Sumedang City, with a hypocenter of 5 km. This earthquake is categorized as a shallow earthquake (M<60) caused by active fault activity that has not been previously mapped. This research aims to relocate the hypocenter of the earthquake in the Sumedang area using the Hypocenter Double Difference (HypoDD) method to be more accurate. The data used is data arrival time BMKG on December 31, 2023 - January 4, 2024, in the Sumedang, with regional restrictions 107.93'E - 107.96'E and 6.76'S - 6.85'S. This study shows Root Mean Square (RMS), which is better than before the relocation. Based on the results, the hypocenter obtained was 12 km, and a cluster was formed at 6-10 km depth. The results of the hypocenter of this earthquake are related to tectonic conditions in the Sumedang area, namely the suspected existence of an active fault.

Keywords: Double Difference; Earthquake; Hypocenter; HypoDD; Relocation; Sumedang.

Introduction

Sumedang is one of the areas located in West Java Province. Three fault structures are essential in West Java: the Cimandiri Fault, the Baribis Fault, and the Lembang Fault.[1] This is supported by the opinion of Van Bemmelen[2] in 1949, who first introduced these faults and suspected that these three faults are still active today. Because Therefore, the Sumedang Regency area is an earthquake-prone area which originates from several active faults on land[3] that have been mapped, such as the Cimandiri Fault, Cugenang Fault, Lembang Fault, Cipamingkis Fault, Garsela Fault, Baribis Fault, Cicalengka Fault, Cileunyi Tanjungsari Fault, Tomo Fault and Cipeles Fault, as well as other active faults that have not been mapped.

According to the physiographic zone, the Sumedang area is included in the Bogor Zone with geological characteristics in the form of a series of Tertiary marine sedimentary rocks, mainly consisting of clay, marl, tuff clay, and sandstone with volcanic deposits.[4] Based on the Geological Map of Indonesia, Bandung Sheet, West Java[5] (**Figure 1**) and the Arjawinangun Sheet, West Java[6] The research area is composed of rock types consisting of alluvial, young volcano products, and old volcano products. The weathering of volcanic rocks produces weathered rock and residual soil that make up the slopes in the study area. This residual soil is loose and susceptible to erosion and landslides.[7]

On Sunday, December 31 2023, an earthquake measuring M=4.8 occurred at 20.34 WIB in Sumedang Regency, with the epicentre at coordinates 6.85'S and 107.94'E, or precisely on land at a distance of 2 km North East from the centre of Sumedang City,

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West Java, with a hypocenter of 5 km. Based on BMKG analysis, the earthquake began with two foreshocks, which occurred at 14.35 WIB with a strength of M=4.1 and at 15.38 WIB with a strength of M=3.4, then followed by several aftershocks with strengths varying between M=2.4 - 4.5. Earthquake activity in the Sumedang area is a type of Shallow Earthquake influenced by local fault activity (strike-slip) in an unmapped area called the Sumedang Fault.[9]

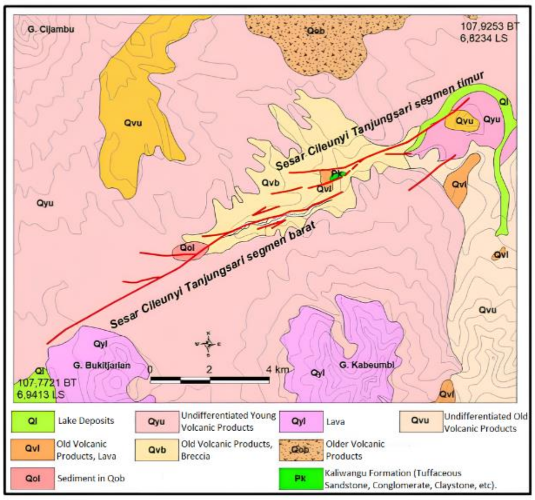


Figure 1. Bandung Sheet Geological Map[5,8]

An earthquake is an event that vibrates or shakes the earth due to the sudden movement of rock layers on the earth's crust and produces energy emitted in all directions in the form of earthquake or seismic waves. When these waves reach the earth's surface, the vibrations can damage everything on the earth's surface, such as buildings and other infrastructure, which can cause fatalities.[10]

Based on this, accuracy and information regarding earthquake parameters it is essential to know so that it can help in disaster mitigation efforts for earthquakes. However, when an earthquake occurs, information on earthquake parameters issued by several institutions, such as BMKG, USGS, and others, often have different observation results. The main difference is in determining the hypocenter of an earthquake. One of the efforts made to know earthquake parameters accurately is by relocating the earthquake hypocenter.

Earthquake hypocenter relocation is a method for recalculating or correcting the position of the hypocenter when an earthquake occurs more accurately.[11] For the study of tectonic processes, earthquake recurrence and event discrimination, precise and accurate earthquake hypocentres are important.[12] The accuracy of the absolute location of the hypocenter is determined by several factors, including the type and number of seismic waves recorded at the station, the geometry of the existing observing station, the accuracy of the arrival time readings and knowledge of the seismic wave velocity structure.[13] Several methods used to determine the hypocenter, namely the manual method (circle method) and the relative method (single event determination method, joint hypocenter determination and double difference), are among the best methods because they can provide solutions that minimize the Root Mean Square. (RMS).[14]

This research was conducted in order to relocate the earthquake hypocenter in the Sumedang area, West Java, with the Hypocenter Double Difference (HypoDD) method more accurately and analyze the distribution of earthquake hypocenters in the Sumedang, West Java, after being relocated.

Methods

The data used in this research is primary data in the form of earthquake arrival time data sourced from the BBMKG Region II catalog with local earthquake data in the Sumedang area for the period December 31, 2023 to January 4, 2024. Data used after completing the catalog filter is 13 events recorded by 63 earthquake recording stations. (**Figure 2**).

The method used in this research is the Double Difference method (HypoDD). Method Double Difference is a relative hypocenter relocation method introduced by Felix Waldhauser and Ellsworth[15] in 2000, and the implementation of this method is software hypoDD version 1.0-03/2001, created to facilitate hypocenter relocation calculations.[16] This method uses intermediate travel time data earthquake pair to an observing station.

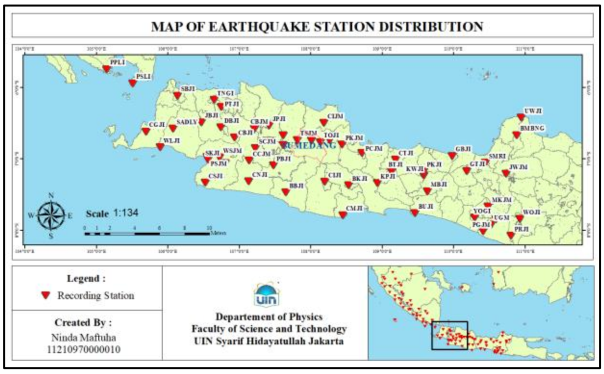


Figure 2. Distribution map of the 63 earthquake recording stations used.

Figure 3 shows that the hypoDD method has an assumption principle that the hypocenter distance between two earthquakes is shorter than the distance between the hypocenter and station; the ray path of the two earthquakes are considered the same, so there is a difference in the travel time between two earthquakes recorded at the same station can be considered only as a function of the distance between the two hypocenters.[15] Hence, the model error speed can be minimized without station correction.

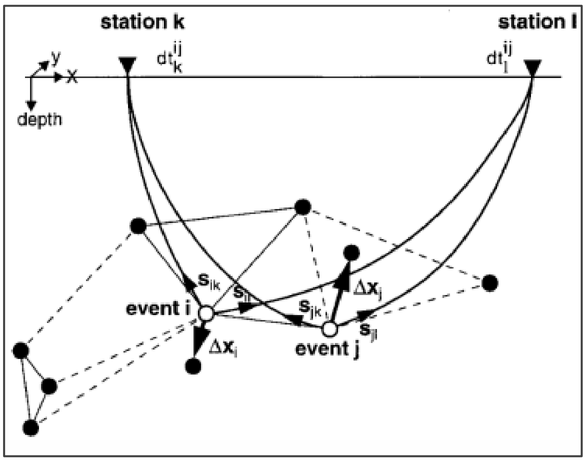


Figure 3. Illustration of the HypoDD method[15]

The primary condition of the Double Difference method is the distance between the two hypocenters. The earthquakes to be relocated must be smaller than the distance between each hypocenter of the station. This method does not require calculations of significant earthquakes (master event), so it can relocate many earthquakes simultaneously with a considerable hypocenter distance distribution.[17]

A residual value close to zero between the difference in travel time calculations and observations of two earthquakes at the recording station is one of the solutions sought in this method.[18] The residual between the calculated travel time and observations of two adjacent earthquakes is defined as follows:

$$dr_k^{ij} = \left(T_k^i - T_k^j\right)^{obs} - \left(T_k^i - T_k^j\right)^{cal} \quad (1)$$

T_k^i is the travel time of an earthquake i to the station k, and T_k^j is the travel time of an earthquake j to the station k. T^{obs} is the observation travel time (recorded by the receiving station, and T^{cal} is the calculation time.

Result and Discussion

To get accurate results, several inputs to the HypoDD program need to be adjusted to produce parameter criteria that match the expected results. Mapping the distribution of earthquake hypocenters is needed to compare hypocenter positions before and after relocation. This mapping process was carried out using ArcGIS software. The result is that the distribution of earthquake hypocenters converges in the villages of Kebonjati and Cimuja, as seen in **Figure 4**.

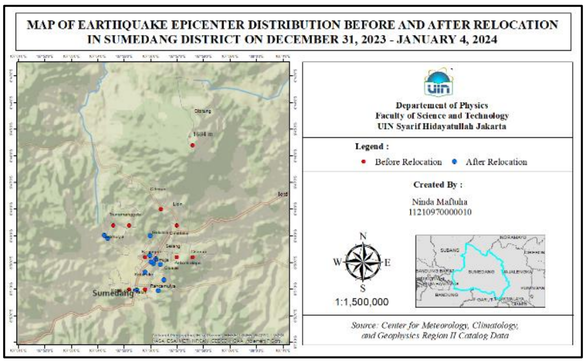
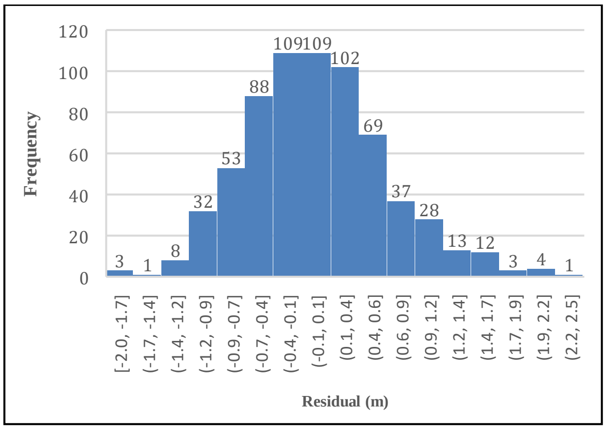


Figure 4. Earthquake Distribution Map Before and After Relocation

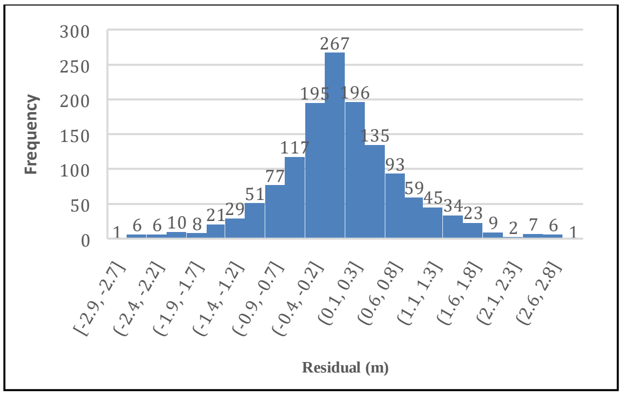
The red colour on the map (**Figure 4**) shows the position of the earthquake before it was relocated, while the blue colour shows the position of the earthquake after it was relocated. Based on these data, the relocation results show a shift in the hypocenter relative to the initial position. Based on the distribution of the relocation results, the position of the earthquake hypocenter has shifted and is more congregated or clustered. The shifts and groupings resulting from this relocation are considered to be associated with or related to the cause of earthquakes. These, namely active faults, have not been previously identified, so the positions of earthquakes that are far apart can be drawn to approach a collection of pairs of earthquakes that have initially been well formed.

The distribution of local earthquake hypocenters that were successfully relocated was 12 events. During the relocation process, there were 1 event earthquakes that were eliminated because they did not comply with the parameters input that the HypoDD program hoped for. These criteria include a maximum hypocentral separation between couples event of 15 km, the maximum distance between pairs event with an observation station of 100 km, and a variation in the damping factor 6. Another factor that could be the reason is an error in the calculation, which causes an airquake. Airquake caused when a pair of earthquakes (event pairs) is near the surface after relocation. If an earthquake does not have a partner, the relocation process cannot be carried out using the Double Difference Method. Thus, relocation results in a Double Difference, often having fewer earthquakes than before relocation.

Apart from shifting the hypocenter position, the relocation results also improve the Root Mean Square (RMS) value, which can be seen using the residual histogram. This can be analyzed from the number of earthquake frequencies with an RMS value close to zero.



(a)



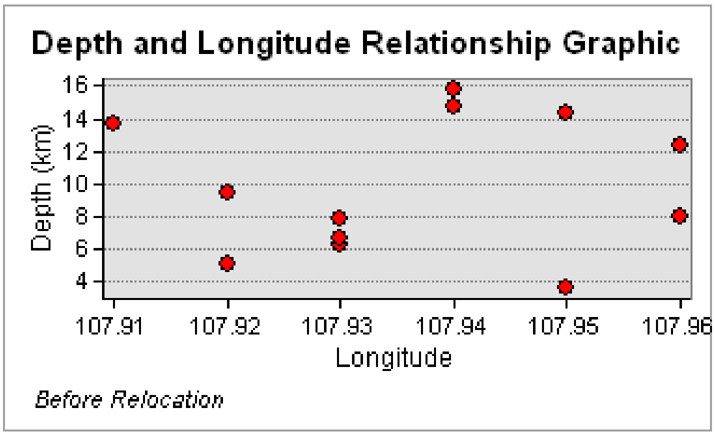
(b)

Figure 5. Histogram of Residual P Wave Travel Time Results of Observations and Calculations. (a) Before Relocation and (b) After Relocation.

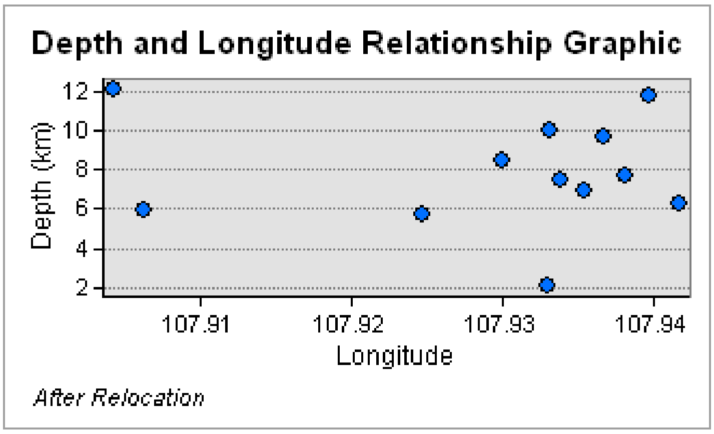
Picture 5(a) shows the residual histogram from the BMKG catalog before relocation. Meanwhile, **Picture 5(b)** is a residual histogram after relocation using the HypoDD program. Looking at the two images, the RMS on the residual histogram after relocation is closer to zero than before relocation. The RMS close to zero on the residual histogram after relocation is 267, while the RMS on the BMKG residual histogram before relocation is more spread out and only around 109. This shows that relocating the earthquake hypocenter using HypoDD provides a better residual value. However, the relocation results using HypoDD need to look at the geological conditions of the research area so that a better and more accurate determination of the earthquake hypocenter can be obtained.

Output from the HypoDD program is hypocenter data that have been relocated by mapping to find outcross section hypocenter distribution after relocation to see the concentration of the hypocenter distribution, both location and depth, so that fault planes in the study area can be identified.

Figure 6 is a map cross-section made perpendicular to the direction of the suspected fault plane in the research area. This image shows the position of the depth distribution of the earthquake hypocenter in the Sumedang area.



(a)



(b)

Figure 6. Cross Section Earthquake Depth (a) Before Relocation and (b) After Relocation

A significant shift in the relocation results using the HypoDD method can be seen in depth. On initial data before relocation, **Figure 6 (a)** has a depth of up to 16 km, while based on the results of the HypoDD relocation **Figure 6 (b)**, the depth of the hypocenter is only at a depth of up to 12 km. Based on the relocation results, the earthquake in the Sumedang area was categorized as a shallow earthquake (H<60 km). For the distribution of earthquake hypocenters after relocation, it can be seen that earthquake points are more clustered in longitude 107.93'S to 107.94'E and more at a depth of 6-10 km (**Figure 6 (b)**). Based on the hypocenter distribution, the Sumedang earthquake has a pattern concentrated in a specific tectonic condition. These tectonic conditions are linked to the cause of the earthquake from December 31 2023, to January 4 2024, alleged consequences of active fault that has never been identified.

Conclusion

Based on the analysis and discussion results, it can be concluded that the relocation results using the Double Difference method produce a better and more accurate hypocenter location. This is characterized by the number of residual frequencies of travel time after relocation, which are close to zero, and the position of the hypocenter distribution, which is more clustered to form a cluster.

Based on the map cross-section after relocation, the depth was found only to reach 12 km and form clusters at a depth of 6-10 km. In contrast, it reached 16 km before relocation, and the earthquake hypocenter was more scattered. Relocation using the Double Difference Method can also improve the depth position. From the distribution of the earthquake hypocenter after relocation, it can be seen that there is a fault area that has never been identified as the cause of the Sumedang earthquake from 31 December 2023 to 4 January 2024 at position 107, 93'E -107.47'E.

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