ANALYSIS OF FAULT PATTERNS THAT CAUSE DESTRUCTIVE EARTHQUAKES IN MAINLAND WEST JAVA

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ABSTRACT

West Java is one of the provinces in Indonesia with a high level of seismicity. During August 2024 alone, there have been 134 earthquakes with 23 earthquakes centered on land. The high seismicity on land is caused by the many faults on the mainland of West Java. This paper presents the results of research on fault patterns in mainland West Java from earthquake data from 1953 - 2023. The data of this research was obtained from the USGS, BMKG, GFZ, IRIS and Global CMT websites. The selected data is an earthquake with a magnitude of ≥ 5 SR and a depth of ≤ 40 km with an area boundary of 5°85´- 8°13´S and 106°74´- 108°76´ E. Using the Focal Mechanism Method, it can be found that the fault pattern that causes earthquakes in West Java in 1953-2023 is 5 reverse fault, 2 Normal fault, and 1 *Strike-slip Fault*. The results of this research are expected to be used as material for the preparation of earthquake disaster mitigation in West Java.

Keywords: Analysis; Fault; Earthquake; West Java.

Introduction

Lately, the Megathrust earthquake has become a fairly intense conversation ranging from experts to the general public. This megathrust earthquake can occur at any time with a magnitude that can reach M 9.9. It is called a Megathrust earthquake because this earthquake occurs in the Megathrust zone. This zone is a subduction zone because the oceanic tectonic plates subtract under the continental tectonic plates. In Indonesia, there are four Megatrust zones, one of which is the Sunda Strait Megathrust and southern Java.[1] This zone is a subduction zone between the Indo-Australian plate and Eurasia. There are experts who say that in this zone, the earthquake is just a matter of time.[2]

The third active plate in Indonesian territory is the Pacific Plate. The activity of these three plates is what causes the high level of seismicity in Indonesia.[3.4] The geodynamics of the three plates are the relative motion of the Pacific Plate to the west and northwest, the Indo-Australian plate moving north, and the Eurasian plate moving south.[5,6] The movement or shifting of these three tectonic plates continues to occur every year. The magnitude of the shifting of these plates depends on the activity of the earth's core because the plates shift due to the heat of the earth's core, which causes the earth's mantle to move. The moving mantle of the earth is what causes the earth's plates to shift.[7]

The high frequency of earthquakes in Indonesia is also caused by the contribution of earthquakes that occurred in West Java Province. BMKG recorded that in August 2024 alone, there were 521 earthquakes in Indonesia.[8] Of these 521 earthquakes, 134 occurred in West Java with 111 earthquakes at sea and 23 centered on land.[9] The high earthquake level in West Java is caused by the area north of the Sunda Strait Megathrust and Southern Java. The presence of West Java in this zone also causes its geological structure to be relatively complex so that in the region fold structures and fault structures develop with high seismicity.[10]

One of the results of the study in this province shows that several districts are in

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areas with a high level of damage risk. These districts include Sukabumi, Cirebon, Pangandaran, Garut, Cianjur, Indramayu, and Tasikmalaya, with an MMI V-VI scale.[11] Seismic research is generally carried out in the context of mitigating the threat of megathrust earthquakes as an effort to reduce risks and casualties.

The sudden release of energy in rocks because they are unable to withstand the force due to the relative motion between plates is the cause of earthquakes.[12] The energy from these earthquakes is in the form of seismic waves that travel towards the surface and cause shocks or vibrations.[13] This relative movement between plates also causes the formation of derivative tectonic structures, such as local faults in almost all islands in Indonesia.[14] The Gasrela Fault is one of the local faults on the West Java mainland that caused a destructive earthquake in Bandung in September 2024.[15]

One of the methods that can be used to analyze fault patterns that cause earthquakes by analyzing the waveforms recorded by a number of seismographs is the Focal Mechanism Solution (FMS). This complete characterization of the seismic focal mechanism provides information on the time of arrival, the location of the epicentre, the depth of focus, the seismic moment, and the magnitude and spatial orientation of the nine components of the tensor moment. This information can be obtained quickly to interpret FMS graphics and is known as a beach ball diagram.[16] This diagram is also known as a three-dimensional Focal Ball that analyzes the direction of motion of the P wave.[17] From this diagram, it will be known that strike (φ), dip (δ) and rake (λ) are the orientation parameters of the fault plane that causes the earthquake.[18] Therefore, with this focal ball, the geometry and fracture mechanism can be characterized.[19] From the propagation of the P wave, the relative motion of the lithosphere can also be known.[20]

Methods

The method used to analyze the fault pattern that causes earthquakes in the mainland of West Java is the Focal Mechanism Solution method. The earthquake data studied in this study is an epithelial earthquake in the mainland of West Java Province. The data used is data from destructive earthquakes that occurred in the period from January 1953 to August 2023 with a magnitude of ≥ 5 SR and a depth of ≤ 40 km. Data was obtained from earthquake catalogues from the USGS, BMKG, IRIS and Global CMT web with region boundaries 5°85′- 8°13′S and 106°74′- 108°76′ E. Table 1 shows the results of sorting from the earthquake data to be studied for fault patterns.

Table 1. Earthquake Historical Data

Date	Late	Long	Depth (km)	Mag. (RS)
09/02/1975	-6,7	106,7	27	5,9
10/02/1982	-6,9	106,9	39,8	6
13/04/1990	-7,1	106,7	33	5,6
06/07/1990	-6,7	108,5	15	6
30/01/1991	-7,3	106,7	33	5,6
13/07/1999	-7,1	107,1	33	5,2
05/06/2000	-7,4	106,7	33	5,1
12/07/2000	-6,7	106,8	33	5,4
25/10/2000	-7,5	107,8	33	5,8
07/04/2002	-7,6	107,9	15	5,8
16/03/2006	-7,4	106,7	20	5
10/03/2020	-6,8	106,7	10	5,6
21/11/2022	-6,8	106,9	10	5,6

From the above data, with the help of ArcGIS 10.8 software, it will be possible to map the pattern of earthquake distribution with the epicentre of the earthquake on the mainland of West Java. Subsequently, with the same software, the focus mechanism analysis was carried out using parameters that had been obtained from the IRIS and GFZ catalogues. These parameters include coordinates, strikes, dips, and rakes that are input into the MS Excel program. The results of this process will be displayed as a map of the distribution of the earthquake mechanism in the form of a focus ball. From each of these focus balls, the type of fault and the direction of movement of the fault can be explained.

Result and Discussion

As stated in the introduction, West Java is an area with high seismicity. From the data obtained from USGS and BMKG for earthquakes whose source is on land alone, there were thirteen destructive earthquakes with a magnitude of ≥ 5 SR and a depth of ≤ 40 km. This earthquake occurred in the time period 1953-2023 (Table 1). Of these thirteen earthquakes, one occurred in Cirebon Regency, Cianjur Regency, Bogor Regency and Bogor City, twice in Garut Regency, and 7 times in Sukabumi Regency. Figure 1 shows a seismic map showing the distribution of epicenters from the earthquake data.

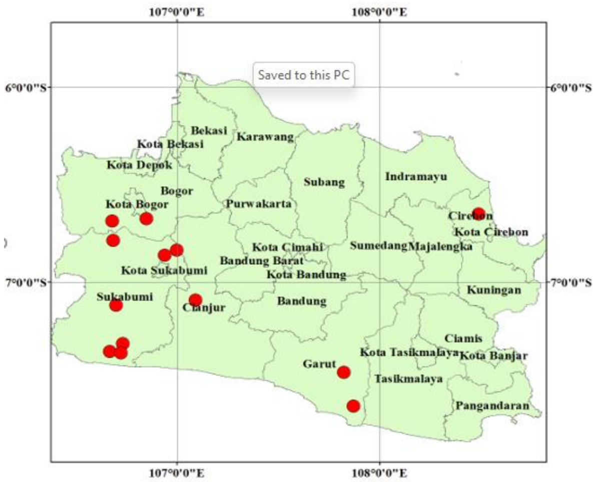


Figure 1. Map of West Java Seismicity

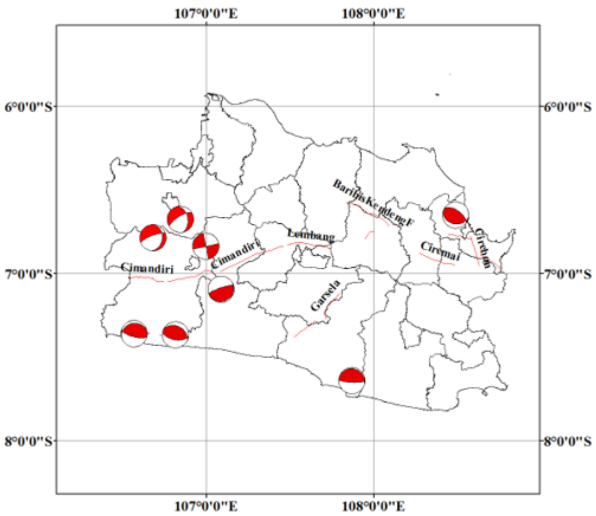


Figure 2. Distribution Map of the Focus Mechanism of the West Java Earthquake

From the earthquake parameters obtained from the IRIS and GFZ catalogues, then using ArcGis 10.8 software, the focus mechanism was obtained, From thirteen earthquake data, eight data were analyzed for fault patterns. Figure 2 shows the distribution of the Focus Mechanism of eight earthquakes in West Java based on the criteria above. Furthermore, to determine the pattern or type of fault of the focus ball in this image, the strike, dip and rake values are studied.

The provisions for determining the fault pattern include if the dip value $\delta \neq 0°$ a//or $\delta \neq 90°$ for normal fault and reverse fault, while $\delta = 90°$ for strike-slip fault. If *the rake* (λ) is positive > 0° for the reverse fault and values negative < 0° for the normal fault. For strike-slip fault with a value of $\lambda = 0°$ is a *left-lateral fault*, and $\lambda = 180°$ is a *right-lateral fault*. The strike value explains the direction of the fault. Of the thirteen earthquake data as shown in Table 1, eight can be analyzed for their fault patterns Table 2 shows the strike, dip and rake values of the Earthquake Focus Mechanism in West Java.

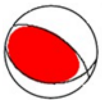
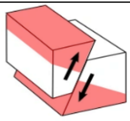
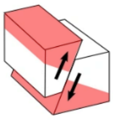
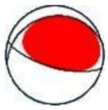
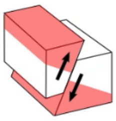
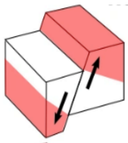
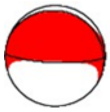
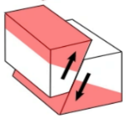
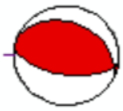
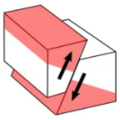
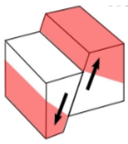
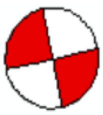
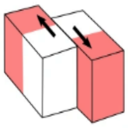
Table 2. Data on the Focus Mechanism of the West Java Earthquake

Date	Strike	Dip	Rake
06/07/1990	98	33	67
13/07/1999	62	11	82
05/06/2000	259	23	65
12/07/2000	350	42	-152
07/04/2002	291	12	109
16/03/2006	295	33	104
10/03/2020	6	30	-150
21/11/2022	348	89	178

From Figure 2 and Table 2, it can be seen that on July 6th, 1990, the first earthquake occurred in Cirebon Regency. From the strike value of 98°, dip of 33° and rake of 67°, it shows that the direction of movement of the fault is in the direction of 98° with a fault slope of 33° and a rake with a positive value (67°). The results of the analysis of the focal sphere show that this earthquake is caused by the activity of a reverse fault. This result is also shown by the focal sphere area which depicts the presence of a compression region between the dilatations.

The second earthquake occurred on July 13th, 1999 in Cianjur Regency. From the fault parameters, it can be seen that the strike value is 62°, the dip is 11° and the rake is 82°. From this data, it shows that the direction of movement of the fault is in the direction of 62° with a slope of 11° and a rake with a positive value (82°). The results of the analysis of the focal sphere show that this earthquake is caused by the activity of a reverse fault.

Table 3. Fault Patterns Causing West Java Earthquakes

Date	Beachball	Fault
6/07/1990		
13/07/1999		
5/06/2000		
12/06/2000		
7/04/2002		
16/03/2006		
10/03/2020		
21/11/2022		

The third earthquake occurred on June 5th, 2000, in Sukabumi Regency. From the fault parameters with a strike value of 259°, a dip of 23°, and a rake of 65°, it shows that the direction of movement of the fault is in the direction of 259° with a fault slope of 23° and a rake with a positive value (65°). These results show that reverse faults are the cause of this earthquake.

The fourth earthquake occurred on July 12th, 2000 in Bogor City. From the fault parameters, a strike value of 350°, a dip of 42° and a rake of -152° were obtained. From this data, it shows that the direction of movement of the fault is in the direction of 350° with a fault slope of 42° and a negative rake (-152°). This negative rake indicates that normal fault are the cause of this earthquake.

The fifth earthquake occurred on April 7th, 2002 in Garut Regency. From the results of the analysis of the focal ball, it can be explained that this earthquake event is caused by the activity of an reverse fault. This is also indicated by the compression area located between the dilatations. From a strike value of 291°, a dip of 12°, and a rake of 109° also indicate that the type of fault is an reverse fault.

The sixth earthquake occurred on March 16th, 2006 in Sukabumi Regency. The results of the analysis of the focal ball show that this earthquake event is caused by the activity of a reverse fault. This is also evidenced by the focal sphere area where the compression region is between the dilatations. From the analysis of the fault parameters, a strike value of 295°, a dip of 33°, and a rake of 104° were obtained. These values show that the direction of movement of the fault is in the direction of 295° with a fault slope of 33° and a rake with a positive value (104°). This data also shows that the reverse fault is the cause of this earthquake.

The seventh earthquake occurred on March 10th, 2020, in Sukabumi Regency. The results of the analysis of the focal ball can be explained that this earthquake is caused by the activity of a normal fault. This is also shown from the focal sphere, where the dilatation area is between the compression areas. Thus, if analyzed from the fault parameters with a strike value of 6°, a dip of 30°, and a rake of -150°, indicating that the direction of movement of the fault is at the coordinates of 6° from the north. With a fault slope of 30° and a negative rake value (-150°), it is clear that the earthquake in Sukabumi Regency was caused by normal fault activity.

The eighth or last earthquake event in accordance with the limits and time period as stated above occurred on November 21st, 2022, whose earthquake source was on the mainland of Cianjur Regency. The results of the focus ball analysis can be explained by the fact that the activity of a strike-slip fault caused this earthquake event. The results of the analysis of fault parameters from strike values of 348°, dip of 89°, and rake of 178° show that the direction of fault movement is at the coordinates of 348° from the north with a fault slope of 89° and a rake value of positive (178°). From the dip and rake values obtained where $\delta = 89$ is close to 90° and $\lambda = 178°$ is close to 180°, this type of fault is interpreted as a strike-slip fault or right lateral slip fault.

The results of the analysis of the eight focus spheres describing the types or patterns in the eight earthquake locations above can be summarized in the following Table 3;

From the data in Table 3 and from the description above, in West Java, there have been eight destructive earthquakes from January 1953 to August 2023 with a magnitude of ≥ 5 SR and a depth of ≤ 40 km. This earthquake was caused by the activity of three types of faults, namely five thrust faults, two normal faults and one shear fault. All of these faults are located on the mainland of West Java Province, so the epicentre of the earthquake is on land. From the dominance of thrust faults in a northerly direction that caused this earthquake, it can be assumed that this fault was the result of activity in the Megathrust zone. This is also in accordance with previous opinions that the Megathrust zone causes a relatively complex geological structure to form fold and fault structures. This structure is what causes the high level of seismicity in West Java. The Megathrust Zone or Subduction Zone is a convergent plate boundary that extends from the north (West of Sumatra) to the south and extends to the south of Java and Nusa Tenggara. The convergent plate boundary between the Indo-Australian Plate and the Eurasian Plate occurs in the western and southern Indonesian archipelago which forms the Sunda Arc.[21] The interaction between the plates in this zone, in addition to causing the formation of folds and faults, also causes land subsidence and so on. Other secondary impacts are the formation of troughs, non-volcanic outer arcs, forearc, volcanic arcs, and back-arc basins.[21,22] As a result of this subduction zone, three dominant structures were also formed on the land of West Java, namely the Maratus Pattern, the Sunda Pattern and the Java Pattern. The geological structures formed as manifestations of the three patterns include the Cimandiri Fault as an interpretation of the Meratus Pattern, the Sunda Basin and the Arjuna Basin as an interpretation of the Sunda Pattern and the Baribis Fault as an interpretation of the Java Pattern.[22] Therefore, the eight earthquake events whose fault patterns were studied in this study were also caused by the activity of these three dominant structures

Conclusion

Of the eight earthquakes in West Java between 1953 and 2023, most were caused by thrust fault activity, namely five events. The other three earthquakes were caused by two thrust faults and one strike-slip fault. During this period, there were three earthquakes in Sukabumi caused by two thrust fault activities and one normal fault. Two earthquakes in Cianjur were caused by thrust fault activity and strike-slip faults. In Cirebon and Garut, there was one earthquake each due to thrust faults and in Bogor, there was also one earthquake due to normal faults. From the types or patterns of faults studied, the role of the subduction zone in the formation and activity of these faults is increasingly clear.

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