

## Tensile Foreshock and Aftershock Earthquakes Characteristic for Subduction (Case Study: Aceh Earthquake In 2004 And Tohoku Earthquake, Japan 2011)

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### Abstract

Aceh earthquake occurred in 2004 with magnitude 8.8Mw, the epicenter was located at latitude 3.295 and longitude 95.982 and Tohoku earthquake occurred in 2011 with magnitude 9.0Mw and located at latitude 38.29 and longitude 142.373. The both earthquakes have similar earthquake source mechanism such as the epicenter located in subduction zone, plate movement type. The research aims to determine the distribution of earthquake events before (foreshock) and after (aftershock) the main shock. Earthquake event datas were obtained from several earthquake databases, such as USGS and BMKG. The earthquake events from database sources are grouped based on the time of occurrence, radius, and magnitude. The result for foreshock shows that the number of earthquake events for foreshock within two years at a radius of 150 km with a magnitude  $M > 4$  as many as 12 earthquake events and 129 earthquake events for Aceh and Tohoku respectively, The result for aftershocks are 119 and 1576 for Aceh and Tohoku respectively.

**Key words:** Foreshock earthquake, Aftershock earthquake

### 1. Introduction

Geographically, Indonesia is in the plate movement of the world (figure 1), in the west the plate movement averages 70mm/year and 120mm/year in the eastern part of Indonesia [1-3]. This shows that plate movement in Indonesia is very active. Several large earthquakes  $>4Mw$  often occur in the territory of Indonesia, it is recorded almost 70,000 earthquake events from 1779-2021 (figure 2)[3]-5]. The big earthquake that occurred in Aceh on December 26, 2004 with a magnitude of  $M > 9.0$  caused a tsunami, thus the impact of this earthquake was felt by several neighboring countries. The mechanism of the aceh earthquake is the interlate movement which is in subduction [6].

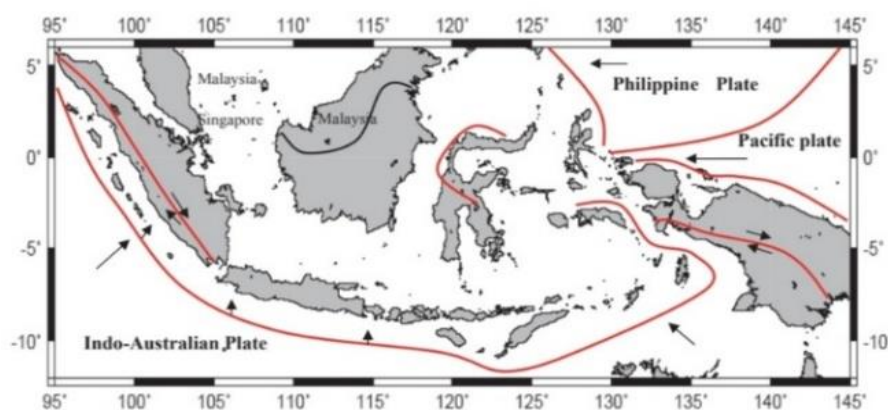


Figure 1. Map of Indonesia and Active Plate [5]

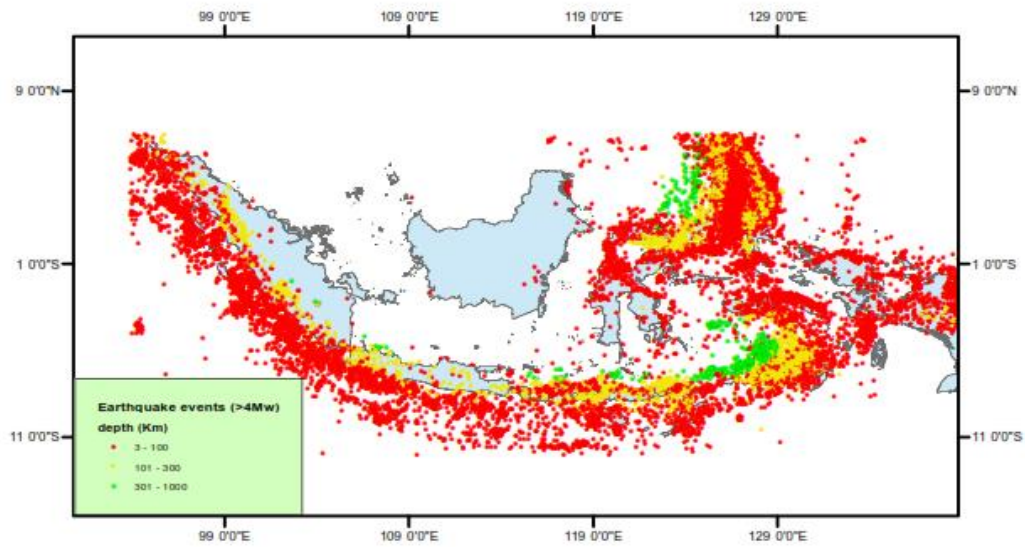


Figure 2. Map of Earthquake Occurrence 1779-2021

The Tohoku Earthquake occurred on March 11, 2011 at 14:46 JST (05:46 UTC). An earthquake measures 9.0Mw with an epicenter off the coast of Sanriku. This is the strongest earthquake that Japan has experienced since the earthquake in Japan. According to the Japan Meteorology Agency (JMA), the earthquake's epicenter was at 130 km east-southeast of the Oshika Peninsula at 38°06.2' North Latitude and 142°51.6' East Longitude and at a depth of 24 km. That is the mechanism of this earthquake is the movement of the plate in subduction with the reverse fault direction [7]. The location of the main earthquake epicenter, and the larger aftershock (moment magnitude M 6), are shown in Fig. 3. The largest aftershock occurred on the same day at 15:15 in the off the coast of Ibaraki Prefecture. On March 9, two days before the main earthquake, the M 7.3 earthquake, which is considered an initial earthquake, occurred off the coast of Sanriku; This is also shown in the figure. The aftershock activity was very intense, which is in the three months between March 11 and June 11, there were five aftershocks with a magnitude of M 7.0 or higher, 82 aftershocks of M 6.0 or higher, and 506 aftershocks with a magnitude of M 5.0. or higher [8-10].

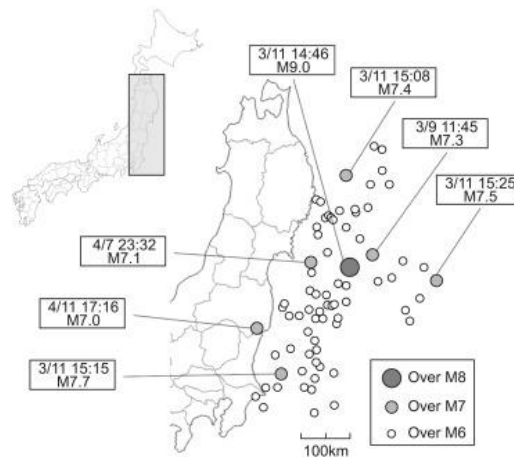


Figure 3. Map of Aftershocks after Mainshock Earthquake [10]

**1.1 Foreshock**

A foreshock earthquake is an earthquake that occurs before the main earthquake. Foreshocks are usually followed by a main earthquake with an energy greater than a foreshock earthquake. Sometimes, it is difficult to determine the foreshock which followed by the main earthquake due to it is influenced by energy, distance and time of occurrence [11,12].

1.2 *Mainshock*

Mainshock is also mentioned as the main earthquake which has a greater earthquake energy. The condition in the mainshock is almost all of the energy from plate movement has occurred. There are many examples of large earthquakes such as Padang earthquake in 2009, Palu earthquake in 2018 and Bali earthquake in 2018. A major earthquake with a large energy and shallow depth will pose a greater risk to buildings and people. This disaster risk reduction really needs to be undertaken such as building construction following earthquake-safe building standards, having building locations that are zoning including safe zones from the effects of earthquake shocks [11-13].

1.3 *Aftershock*

Aftershock is a small earthquake that occurs after a mainshock earthquake or commonly known as aftershocks. Aftershock energy is usually smaller than the main earthquake. These earthquakes appeared until conditions of movement stabilized again [11], several major earthquakes that were not followed by aftershocks such as the earthquake that occurred in Mentawai in November 2020.

2. **Research Method**

Data for the occurrence of foreshock and aftershock earthquakes for the Aceh earthquake and the Tohoku earthquake, Japan were gained from the USGS and BMKG databases which were grouped by time 0-3 months, 3-6 months, 6-9 months, 9-12 months, 12-15 months 15-months. 18 months, 18-21 months and 21-24 months, based on a distance of 0-50 Km, 50-100 Km and 100-150 Km., and based on the strength of the earthquake, namely 4-8Mw. The research flow is as described in Figure 4.

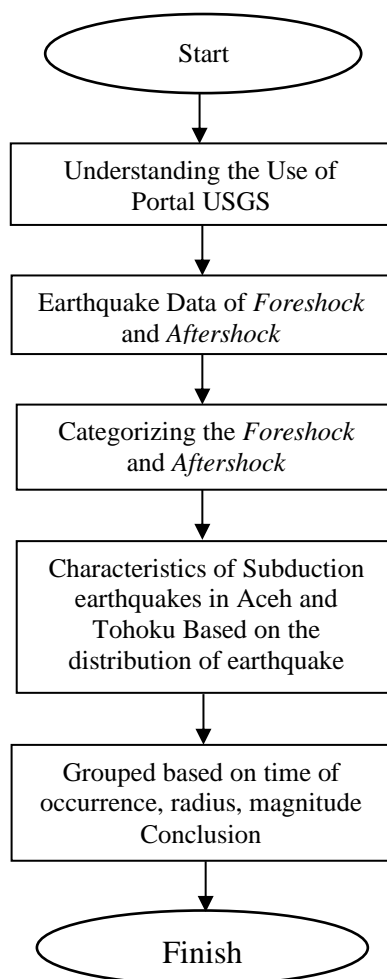


Figure 4. Research flowchart

3. Results

Results of Data Processing Research data is grouped based on the duration of time. The occurrence with a period of two years before and after the main earthquake, based on a radius of 150 km from the main earthquake epicenter, and based on magnitude > 4.

3.1 Foreshock earthquake based on the occurrence of time

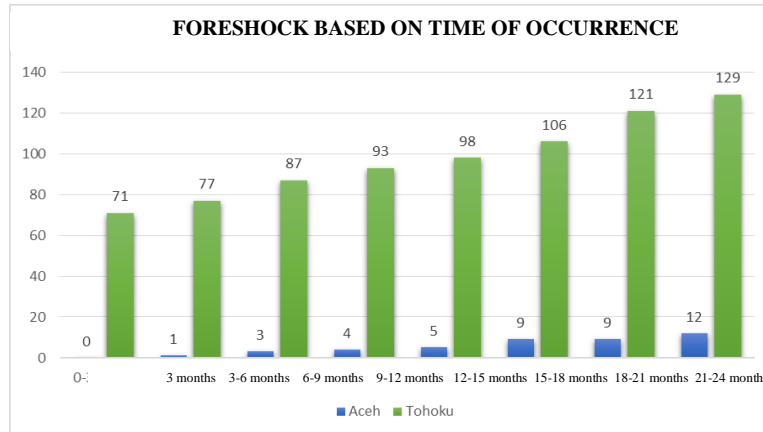


Figure 5. Occurrence Distribution Based on Time

Table 1. Foreschock Earthquake Based on Time of Occurrence

Time	Aceh		Tohoku	
	Total	Accumulative	Total	Accumulative
0-3 months	0	0	71	71
3-6 months	1	1	6	77
6-9 months	2	3	10	87
9-12 months	1	4	6	93
12-15 months	1	5	5	98
15-18 months	4	9	8	106
18-21 months	0	9	15	121
21-24 months	3	12	8	129

Based on table 1 and figure 5, the foreshock earthquake in a period of two years at a radius of 150 km with a strength of  $M > 4$ , which is 12 earthquake events, the result is lower than the foreshock earthquake that occurred in Tohoku Japan, which is 129 earthquakes.

3.2 Aftershock earthquake based on the occurrence of time

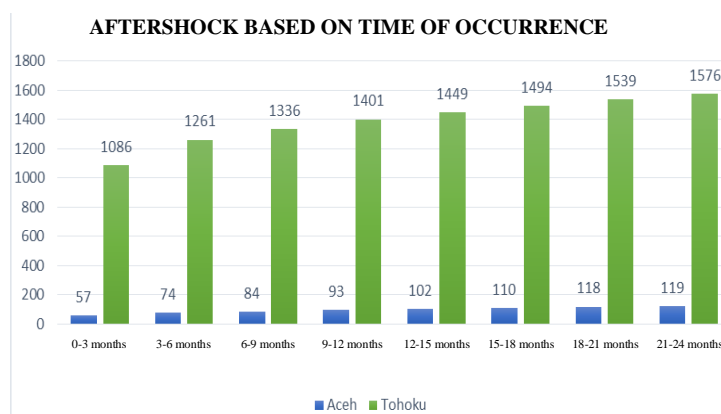


Figure 6. Occurrence Distribution of Aftershock Earthquake

Table 2. Aftershock Earthquake Based on Time of Occurrence

Aftershock Based on Time of Occurrence				
Time	Aceh		Tohoku	
	Total	Accumulative	Total	Accumulative
0-3 months	57	57	1086	1086
3-6 months	17	74	175	1261
6-9 months	10	84	75	1336
9-12 months	9	93	65	1401
12-15 months	9	102	48	1449
15-18 months	8	110	45	1494
18-21 months	8	118	45	1539
21-24 months	1	119	37	1576

Based on the table 2 and figure 6, the activity of the precursor earthquake after the main earthquake for a duration of two years at a radius of 150 km with a strength is  $M > 4$ . The results reveal that in the Aceh region has 119 earthquakes, these results are compared with the results of the Tohoku earthquake, which has more earthquakes with a total of 1576 earthquakes.

### 3.3 Foreshock earthquake based on distance (radius)

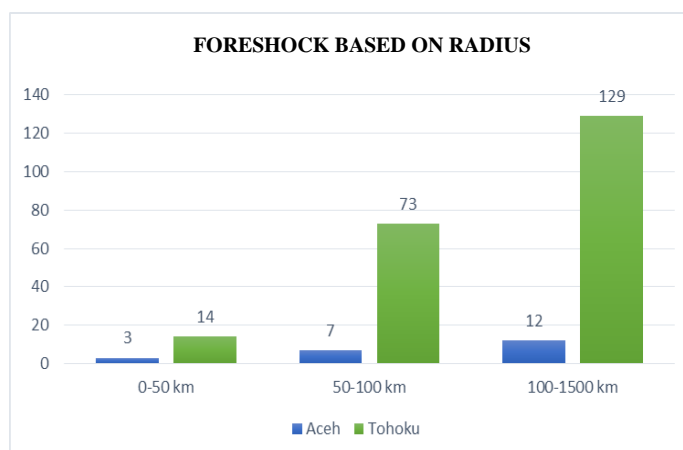


Figure 7. Distribution of foreshock earthquake

Table 3. Foreshock Earthquake Based on Radius

Foreshock Based on Radius				
Radius	Aceh		Tohoku	
	Total	Accumulative	Total	Accumulative
0-50 km	3	3	14	14
50-100 km	4	7	59	73
100-1500 km	5	12	56	129

Table 3 and figure 7 show the occurrence of foreshock earthquakes based on distances at a radius of 0-50 km from the main earthquake center are 3 earthquakes, 4 earthquakes are recorded at a radius of 50-100 km, and 5 earthquakes at a radius of 100-150 km. Compared to the earthquakes in Aceh, the Tohoku earthquake that is occurred more earthquakes, at a radius of 0-50 km experience 14 earthquakes, 59 earthquakes are recorded at a radius of 50-100 km, and 56 earthquakes have occurred at a radius of 100-150 km.

**3.4 Aftershock earthquake based on radius**

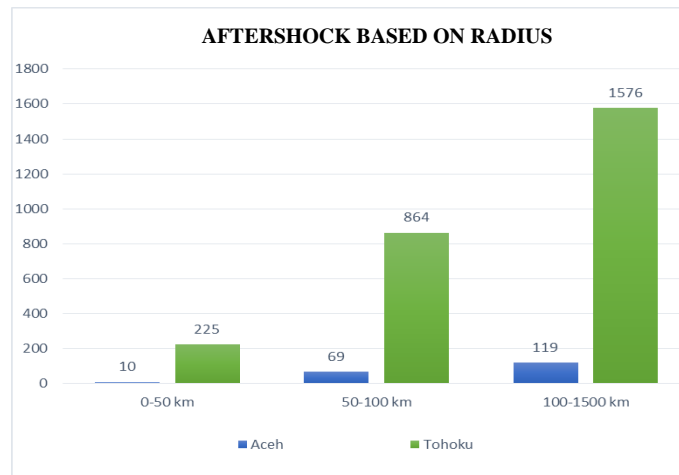


Figure 8. Distribution of aftershock earthquake

Table 4. Aftershock Earthquake Based on Radius

Radius	Aceh		Tohoku	
	Total	Accumulative	Total	Accumulative
0-50 km	10	10	225	225
50-100 km	59	69	639	864
100-1500 km	50	119	712	1576

Based on the table 4 and figure 8, 10 earthquakes are recorded at a radius of 0-50 km from the main earthquake center, 59 earthquakes are recorded at a radius of 50-100 km, and 50 earthquakes occurs at a radius of 100-150 km. Compared to the earthquake in Aceh, the Tohoku earthquake occurred are more frequently, at a radius of 0-50 km occurs 225 earthquakes, at a radius of 50-100 km occurs 639 earthquakes, and at a radius of 100-150 km occurs 712 earthquakes.

**3.5 Foreshock Earthquake based on magnitude**

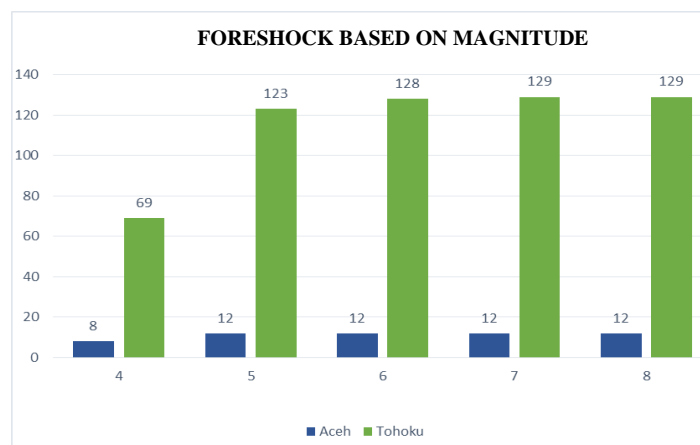


Figure 9. Distribution of Foreshock Earthquake Based on Magnitude

Table 5. Foreshock Earthquake Based on Magnitude

Radius	Foreshock Based on Magnitude			
	Aceh		Tohoku	
	Total	Accumulative	Total	Accumulative
4	8	8	69	69
5	4	12	54	123
6	0	12	5	128
7	0	12	1	129
8	0	12	0	129

Figure 9 and table 5, foreshock earthquakes in the Aceh region with a duration of 2 years at a radius of 150 km are recorded at M strength > 4, 8 earthquakes have occurred, and 4 earthquakes have occurred in M > 5. The results of the earthquake in Tohoku are more common than the Aceh earthquake, at magnitude M > 4 has occurred 69 earthquakes, at the magnitude of M > 5 earthquakes has occurred 54 times, at the strength of M > 6 has occurred 5 earthquakes, and M > 7 has occurred 1 earthquake.

**3.6 Aftershock earthquake based on magnitude**

Figure 10 and table 6 foreshock earthquakes in the Aceh region with a duration of 2 years at a radius of 150 km recorded at strength M > 4 have occurred as many as 79 earthquakes, 39 have occurred earthquakes at M > 5, and at M > 6 have occurred one earthquake. The results of the earthquake in Tohoku are more common than the Aceh earthquake, at magnitude M > 4 has occurred 867 earthquakes, at strength M > 5 earthquakes has occurred 673 times, at strength M > 6 and it has occurred 34 earthquakes, and M > 7 has occurred 2 earthquakes.

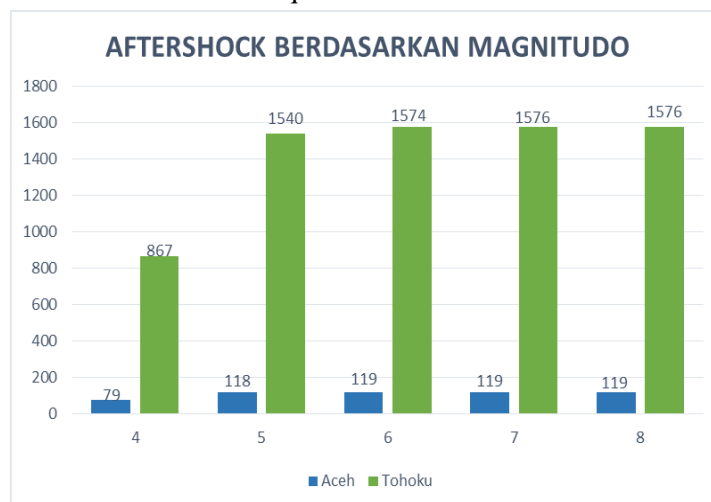


Figure 10. Aftershock Earthquake Based on Magnitude

Table 6. Aftershock Earthquake Based on Magnitude

Radius	Aftershock Based on Magnitude			
	Aceh		Tohoku	
	Total	Accumulative	Total	Accumulative
4	79	79	867	867
5	39	118	673	1540
6	1	119	34	1574
7	0	119	2	1576
8	0	119	0	1576

3.7 Result of overall for foreshock and aftershock earthquakes with magnitude > 4

Based on the recapitulation results table 7 and figure 11, the foreshock earthquake in Aceh has occurred 12 times, the number is less than the Tohoku earthquake which has occurred as many as 129 earthquakes. Aftershock earthquakes in Aceh accumulated are 119 earthquakes, this number is less than the Tohoku earthquake which has occurred as many as 1576 earthquakes.

Table 7. Recapitulation result of foreshock dan aftershock earthquakes with magnitude > 4,

Magnitudo	Radius 0-50 km				Radius 50-100 km				Radius 100-150 km			
	Aceh		Tohoku		Aceh		Tohoku		Aceh		Tohoku	
	Foreshock	Aftershock	Foreshock	Aftershock	Foreshock	Aftershock	Foreshock	Aftershock	Foreshock	Aftershock	Foreshock	Aftershock
4	2	7	8	196	2	40	18	325	4	32	44	402
5	1	3	3	25	2	19	39	296	1	18	12	299
6	0	0	3	4	0	0	1	17	0	0	1	10
7	0	0	0	0	0	0	1	1	0	0	0	1
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0

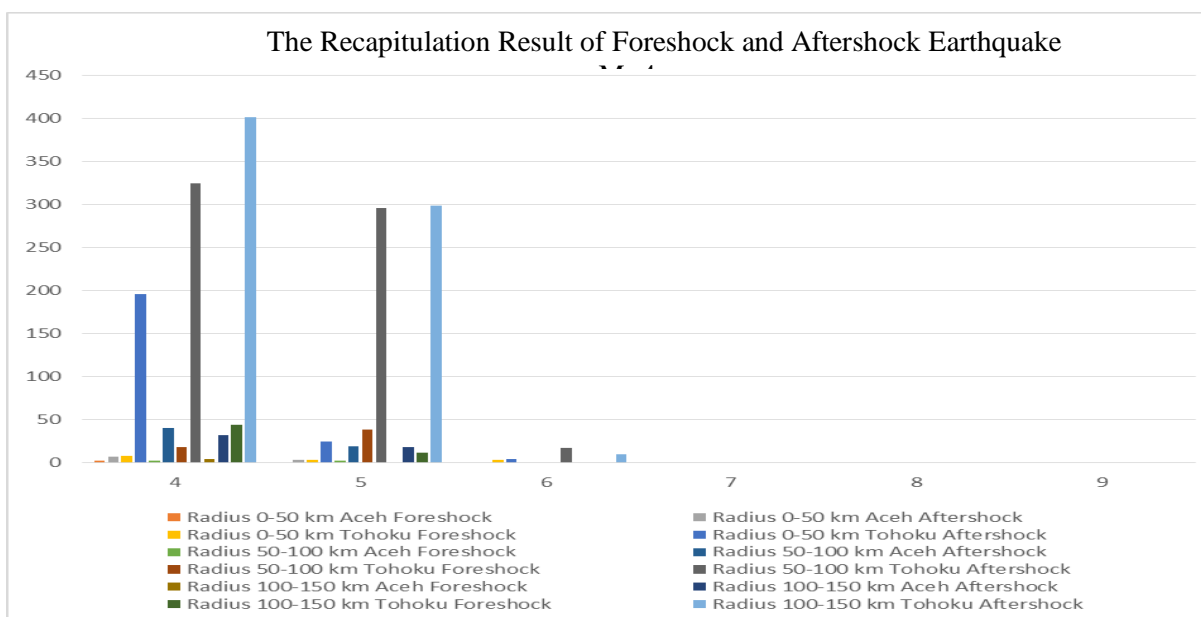


Figure 11. Recapitulation Result of Foreshock and Aftershock Earthquake M> 4

4. Conclusion

Dealing with the results of the analysis of the characteristics of the foreshock and aftershock earthquakes for the subduction earthquake of Aceh earthquake in 2004 and Tohoku earthquake in 2011, it can be concluded that the characteristics of the predecessor earthquake with a duration of 2 years at a radius of 150 km with a strength of  $M > 4$  in Aceh occurred were 12 earthquakes and it was lower than the earthquake in Tohoku which occurred as many as 129 earthquakes. From the results of the characteristic aftershocks in Aceh within a period of 2 years at a radius of 150 km with a strength of  $M > 4$  occurred 119, so then the result was lower than the earthquake in Tohoku which occurred as many as 1576 earthquakes.

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