Use of Borehole Seismometers in Earthquake Monitoring at the Baribis Fault Leading to Jakarta, Western Java

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Abstract

The region of Jakarta and its vicinity is one of the least understood geological domains in Java Island, Indonesia. Yet, the region is one of the few places which are often impacted by earthquakes from the Indo-Australian Plate subduction zone as well as on land active faults. In this study, a borehole seismic experiment was designed to unravel the seismic activity of the Baribis Fault, which continues and leads to Jakarta. This passive source experiment was composed of seven broadband instruments that extended across the Jakarta region and surrounding areas. The experiment recorded seismic data from the end of July 2019 to August 2020. We located 91 events of hypocenter location determination of the data recording; one event was located closely to the Baribis Fault line that continues to Jakarta and was felt in Bekasi (Southeast of Jakarta) at up to II-III on the Modified Mercalli Intensity (MMI) scale. The focal mechanism solution of this event shows an oblique thrust fault type. This event is evidence that the Baribis Fault is active.

1. Introduction

The area of Jakarta, the capital city of Indonesia, located in the western part of Java, is a relatively complex geological structure due to the collision of the Indo-Australian Plate with the Eurasian Plate along the Java Trench. In addition, the tectonic activity in this area is caused by three active faults: the Cimandiri, Lembang, and Baribis Faults. These three faults are located closely to areas with high population density. Geological studies related to the Baribis Fault have been carried out (Katili and Soetadi, 1971; Setyadji, 1997; Marliyani, 2016). This particular fault is identified as reverse to strike-slip faulting as observed in topographic and seismic reflections (Marliyani, 2016). Based on a GPS study, the average horizontal displacement of this fault is 1.0–2.1 cm/year (Abidin et al., 2009). By applying ambient noise tomography (ANT), Rosalia et al. (2019) show the existence of the Baribis Fault continuing and leading to Jakarta.

In addition, Jakarta and its surrounding areas are generally located in sedimentary basins which are quite thick. Ridwan et al. (2017) show a bedrock morphology with a depth range of 350–725 meters. This means the area will be severely affected by earthquakes due to the effect of amplification on the basin. Generally, earthquakes felt in the Jakarta area are caused by the subducting slab of the Indo-Australian Plate. One of the most historically significant earthquakes in Batavia (Jakarta), which resulted in fatalities and the collapse of buildings occurred on January 5, 1699. Nguyen et al. (2015) modeled this event which could have been generated by a ~ Mw 8.0 earthquake in the subducting slab at a depth of around 160 km. On January 22, 1780, the largest earthquake to have struck Java occurred (Musson, 2012). As a result, 27 structures collapsed in Batavia (Wichmann, 1918). In a recent seismicity study in the western part of Java, Supendi et al. (2018) identified eight events from 2009 to 2015 in the Baribis Fault Zone in the northern part of West Java; these have a focal mechanism of thrust faulting in the west, oblique in the middle, and strike-slip to the east of West Java. By using the regional network of the Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG), it was determined that the earthquake in Jakarta and the surrounding area was relatively quiet. However, on December 10, 2019, an

M 3.2 earthquake located 22 km southwest of Bekasi took place, which was felt on the II-III MMI scale in Bekasi and the surrounding area.

In this study, earthquake monitoring was carried out by deploying seven borehole seismometers (Fig. 1) around the Baribis Fault in Jakarta and its surrounding area. The Baribis Fault was identified, e.g., through a geological study (Simandjuntak and Barber, 1996) and ANT imaging (Rosalia et al., 2019). Despite these prior studies, many questions remain unanswered regarding the Baribis Fault and its continuation to Jakarta. Our borehole passive source experiment, thus, potentially offers seismic evidence of this fault. This deployment will provide new data that can be compared with that of the existing regional seismic BMKG stations; it will also make possible the discovery of new insights regarding seismicity in this area based on our borehole seismic data.

2. Data And Method

We completed a temporary installation of seven borehole seismometers in July-August 2019, as part of the collaboration between Institut Teknologi Bandung and PT. Resuransi Maipark Indonesia. The two first seismometers were deployed at the end of July 2019; five more seismometers were then deployed in early August 2019. The station design consists of C100 wide band seismometers deployed at a depth of ~ 10 meters below ground level using a PVC pipe (Fig. 2a), while a Geobit digitizer Sri32L was placed on the surface in a mini shelter 1 m³ in size (Fig. 2b and c). The drilling of the borehole was assisted by a digger machine, and the mini shelter was made of iron to protect the instruments from theft or damage (Fig. 2c). The borehole seismic stations were powered by 12 Volt 75 Ah lead-acid car batteries, which were replaced approximately every 1.5 months.

To determine the quality of the seismogram data, the average of the recorded noise level was evaluated using probability density function (PDF) and plotting the power spectral density (PSD) (Fig. 3). First, we removed the mean and detrend, and we deconvolved the instrument response of the seismogram data without prior band pass filtering. The signal was then windowed using the Hanning tapered windows function with a window length of 10 minutes, making sure that each of these windows did not overlap one another. PSD was calculated using a standard FFT algorithm, and the results were interpolated with log space interpolation. The PSD results from all windows at each station were then stacked. The PDF was calculated using an adaptive kernel density estimation algorithm based on a linear diffusion process (Botev and Grotowski, 2010). The PDF creation process was done iteratively to obtain optimal bandwidth by considering the most common linear diffusion with the same stationary density as the estimated pilot density. The program for calculating PDFs with adaptive kernel density estimates was created by Botev (2016). All these processes were evaluated using the vertical seismogram (BHZ) component.

Data processing was then carried out through two stages: (i) events identification using Filter Picker Algorithm (Lomax et al., 2012), and (ii) manual picking of P- and S-wave arrival-times of 3-component waveforms using Seisgram2K (Lomax and Michelini, 2009). The earthquake hypocenters were then determined using the Hypoellipse code (Lahr, 1979). We used the ISOLA package (Sokos and Zahradnik,

2008) to perform moment tensor inversions from the borehole and BMKG seismic stations (see inverted blue and green triangles in Fig. 1). The observed waveforms were pre-processed using a high pass filter with a corner frequency of 0.04 Hz to 0.09 Hz. For hypocenter relocation and focal mechanism determination, we used the 1-D seismic velocity model AK135 (Kennett et al., 1995). As of August 2020, the deployment had already recorded 43 local earthquakes inland and 48 regional earthquakes in the southern part of West Java.

3. Results And Discussion

The background noise signals from seven different stations are shown in Fig. 3. The PDF results show that all stations provide similar results for periods greater than 50 s. Differences between stations were observed in low periods; this represents difference levels of cultural noise between stations. Station BAR4 had the lowest level of cultural noise, whereas the highest was at Station BAR7. One feature of cultural noise is that it has a high diurnal variation; this was represented by a more diffuse PDF distribution at Station BAR7. Generally, the range of differences in the noise level of each borehole station is relatively small compared with installations on the surface (see Miller et al., 2016), which indicates that the installation of a borehole at a station is quite successful in reducing recorded noise.

We located 91 events of hypocenter location determination for one year of data recording with a total 489 and 458 of P- and S-wave arrival times, respectively. To check the reliability of the hypocenter solutions, a Wadati diagram of the arrival time was plotted (Fig. 4). In general, a V_p/V_s ratio of 1.75 was obtained. This value is close to the global average of V_p/V_s data which is 1.73 (Stein and Wysession, 2003), indicating that our picking of P and S wave arrival times was close to the actual arrival times.

Generally, the earthquake hypocenter locations are divided into local and regional earthquakes. Local earthquakes are located inland, while regional earthquakes are located in the southern part of Banten and West Java (Fig. 5a). We identified local earthquakes in four regions: Region 1 located west-southwest (WSW) of Mt. Salak; Region 2 located north of Mt. Gede; Region 3 located south of Purwakarta; and Region 4 located on the Baribis Fault (Fig. 5b). From August to September 2019, there were swarm earthquakes in Region 1. These events occurred ~ 13 km WSW of Mt. Salak-Bogor, West Java (Fig. 5b). Supendi et al. (2018) show that a destructive earthquake occurred in this area on September 8, 2012 (M_L 4.6) with a thrust fault type. Based on the BMKG report, the average magnitude of this event was around M 2.2 to M 4.2. Some of the events were felt by inhabitants, and one event caused structural damage (M 4.2 on August 23, 2019). Our interpretation of this swarm event is that it was probably related to stress change due to volcanic-tectonic activity. In Region 2, we found seven earthquakes located ~ 12 km north of Mt. Gede (Fig. 5b). The three earthquakes that occurred in Region 3 were probably caused by an unidentified local fault in the region.

Finally, in Region 4, we identified two events on the Baribis Fault on December 10, 2019 and March 29, 2020. Interestingly, the event of December 10, 2019 was felt in Bekasi at up to II-III MMI level (Fig. 5b). We located this event using: (i) borehole stations only (red star in Fig. 6), (ii) borehole stations combined with

BMKG stations (yellow star in Fig. 6), and the BMKG stations only (blue star in Fig. 6). The epicenter location determined using borehole stations was ~ 1.8 km south of the Baribis Fault line at a depth of 7.5 km, while the epicenter based on BMKG data was ~ 12.8 km south of the Baribis Fault line at a depth of 4 km depth, and using the combined borehole and BMKG stations, the epicenter was located ~ 7 km south of the Baribis Fault line at a depth of 8.5 km (Fig. 6). We also conducted focal mechanism analysis in order to estimate the type of fault slip for Region 3 events (Fig. 6) using the borehole station (red beach ball), BMKG stations (blue beach ball), and the combined borehole and BMKG stations (yellow beach ball). All three focal mechanism solutions show that it was an oblique thrust fault type. Usually the earthquakes felt in Jakarta and its surroundings are located south of West Java, but the earthquake felt in Bekasi on December 10, 2019, was located inland and closely to the Baribis Fault line, indicating that this earthquake is probably evidence that the Baribis Fault is active.

4. Conclusions

We deployed seven borehole seismometers in Jakarta and the surrounding area. The collected data allow for addressing fundamental scientific questions about the Baribis Fault which continues to Jakarta. Our initial observations and results indicate that one earthquake that was felt in Bekasi was located very close to the Baribis Fault line (~ 1.8 km south of the fault), indicating an oblique thrust fault. In addition, we identified two seismically quite active regions: Region 1 located west-southwest of Mt. Salak-Bogor and Region 2 located north of Mt. Gede-Bogor (Fig. 5b).

Declarations

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Availability of data and material

Earthquake data are available from the co-author (P.S.) upon request.

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Authors' contributions

R.D., S.W., P.S., Y.M.H., Z.Z., D.P.S., E.G. and A.A. conceived the study and contributed to the writing of the manuscript. All authors contributed to the preparation of the manuscript and data acquisition.

Competing Interests Statement

We declare that we have no competing financial, professional, or personal interests that might have influenced the performance or presentation of the work described in this manuscript.

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Figures

Figure 1

Map of the study area; the blue inverted triangles are the borehole seismic stations used in this study; black trace lines represent the Baribis Fault extracted from Simandjuntak and Barber (1996); left inset shows the location of the western part of West Java (red rectangle) with respect to the Indonesian region; right inset shows the location of the study area (black rectangle) with respect to the western part of Java region, the green inverted triangles are the BMKG seismic stations used for Region 4 in Fig. 5b; red traces correspond to the other major crustal faults (including Cimandiri and Lembang Faults) in the region which were extracted from Irsyam et al. (2017).

Figure 2

Photographs of instrumentation and example field sites. (a) C100 wide-band seismometer, (b) Geobit digitizer Sri32L, and (c) borehole instrumentation at BAR6 in Bekasi.

Figure 3

Probability density function (PDF) for stations: (a) BAR1, (b) BAR2, (c) BAR3, (d) BAR4, (e) BAR5, (f) BAR6, and (g) BAR7. Each station was constructed using 9648 power spectral densities (PSDs) from August to November 2019. White dashed lines indicate the boundaries of 90 percent of the data distribution in each period.

Figure 4

Wadati diagram for the 56 events used in this study. The obtained V_p/V_s ratio value is 1.75.

Figure 5

(a) Map of the earthquakes which were recorded and located using borehole seismometers. Black rectangle shows the location of the study area. (b) Distribution of the events inland divided into four regions. Colored dots depict the focal depth of hypocenter. Blue inverted triangles show the borehole seismic stations. Black trace line represents the Baribis Fault taken from Simandjuntak and Barber (1996).

Figure 6

Map of the earthquake epicenter and focal mechanism of the December 10, 2019 event in the Baribis Fault located using borehole stations only (red), BMKG stations only (blue), and the combined borehole and BMKG stations (yellow).