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Seismometer Health Diagnosis Based on Cross Spectral Density Coherence Method in Indonesia Seismic Networks

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ABSTRACT

Evaluation of seismometer health is crucial in accurately detecting earthquake and tsunami events. Currently, seismometer health evaluation is based solely on data quality unrelated to seismometer sensor performance. While seismometers are essential for tracking seismic activity, environmental factors, aging components, and external interference can cause seismometers to function worse over time. This study presents a seismometer health diagnosis technique based on seismic signal analysis, including signal truncation, signal resampling, filtering, and deconvolution of instrument response. Then the proposed method of cross-spectral density coherence to extract seismometer sensor health indicators performed on two adjacent broadband seismic stations by analyzing the frequency domain with a maximum inter-station distance of 100 km. The data used are seismic signals recorded on three-component seismometers (North-South, East-West, Z-Vertical). The coherence value of cross-spectral density is used as an indicator to diagnose seismometer health. The proposed method was evaluated on a seismic network in Indonesia consisting of 88 stations and a teleseismic earthquake event in Honshu, Japan. The coherence values of almost all tested stations are above 0.8, which means good performance. The proposed method is suitable for analyzing the health of seismometers, especially in Indonesia.

Keywords: seismic instrumentation health, broadband seismometer, teleseismic earthquake, coherence cross-spectral density

INTRODUCTION

In Indonesia, the Meteorology, Climatology and Geophysics Agency (BMKG) has 507 broadband stations spread throughout Indonesia (FIGURE 1). Indonesia Tsunami Early Warning System, or InaTEWS, is the name of the earthquake and tsunami monitoring stations. Each station has a seismometer as the main sensor to detect earthquake vibrations. Each earthquake and tsunami observation station in Indonesia has its own uniqueness, such as the location that is easy to reach or difficult to reach, the brand of the seismometer, and the age of the seismometer. Therefore, maintenance of the seismometer sensor performance is very important. Currently, BMKG conducts preventive maintenance and collective maintenance. Preventive maintenance is carried out periodically to reduce costs and downtime [1-2], while corrective maintenance is carried out after total damage has occurred [3-4].

In addition to preventive and corrective maintenance, the most recommended type of maintenance is predictive maintenance, which aims to identify damage to system components, predict the remaining working life of the system, and provide early warning of damage symptoms before a complete breakdown occurs [5-9]. To identify early indicators of damage, predictive maintenance analyzes condition data. There are two models in predictive maintenance: diagnosis and prognosis [10-11]. The diagnosis model is a model that can be built at present. To prevent future fatal damage to earthquake monitoring stations, predictive maintenance is built at BMKG. Seismometers, digitalization, cables, and other circuits are part of earthquake and tsunami observation stations, and seismometers are the main source [12]. Therefore, this study examines the seismic network of seismometers as the most important tool. Seismometers that analyze seismic waves can be used to diagnose diseases [13]. We use the frequency domain, namely the cross-spectral density coherence method, where the frequency domain can analyze complex signals and more easily remove noise [14] to determine the health of seismometers. In this study, we analyzed 88 stations on the islands of Java and Bali that recorded during the January 1, 2024, Honshu, Japan earthquake with a magnitude of 7.5.

FIGURE 1. Distribution of earthquake and tsunami observation stations in Indonesia.

METHOD

We use an earthquake event that occurred on January 1, 2024, in Honshu, Japan, with a depth of 10 km and a magnitude of 7.5. The earthquake event with geophysical stations has a distance of about 5600 km - 9000 km. The data used are broadband seismometer recordings from stations located on the islands of Java and Bali with a recording time span of 800 seconds during rayleigh waves on January 1, 2024, using three components: North-South, East-West, and Z-Vertical. Each station analyzed will be coherent, with three stations located around it with a maximum distance of 200 km. References are used in the design suggested in this study [13-14]. The following FIGURE 2 is a block diagram of this research design.

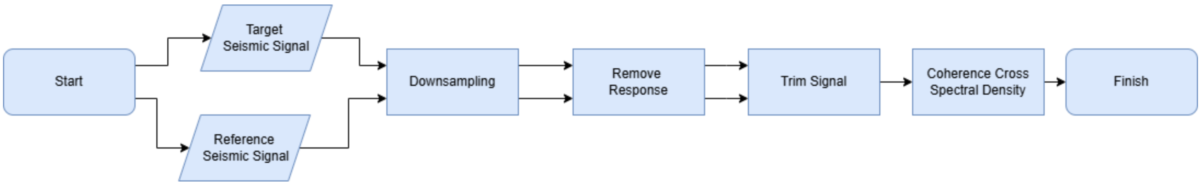
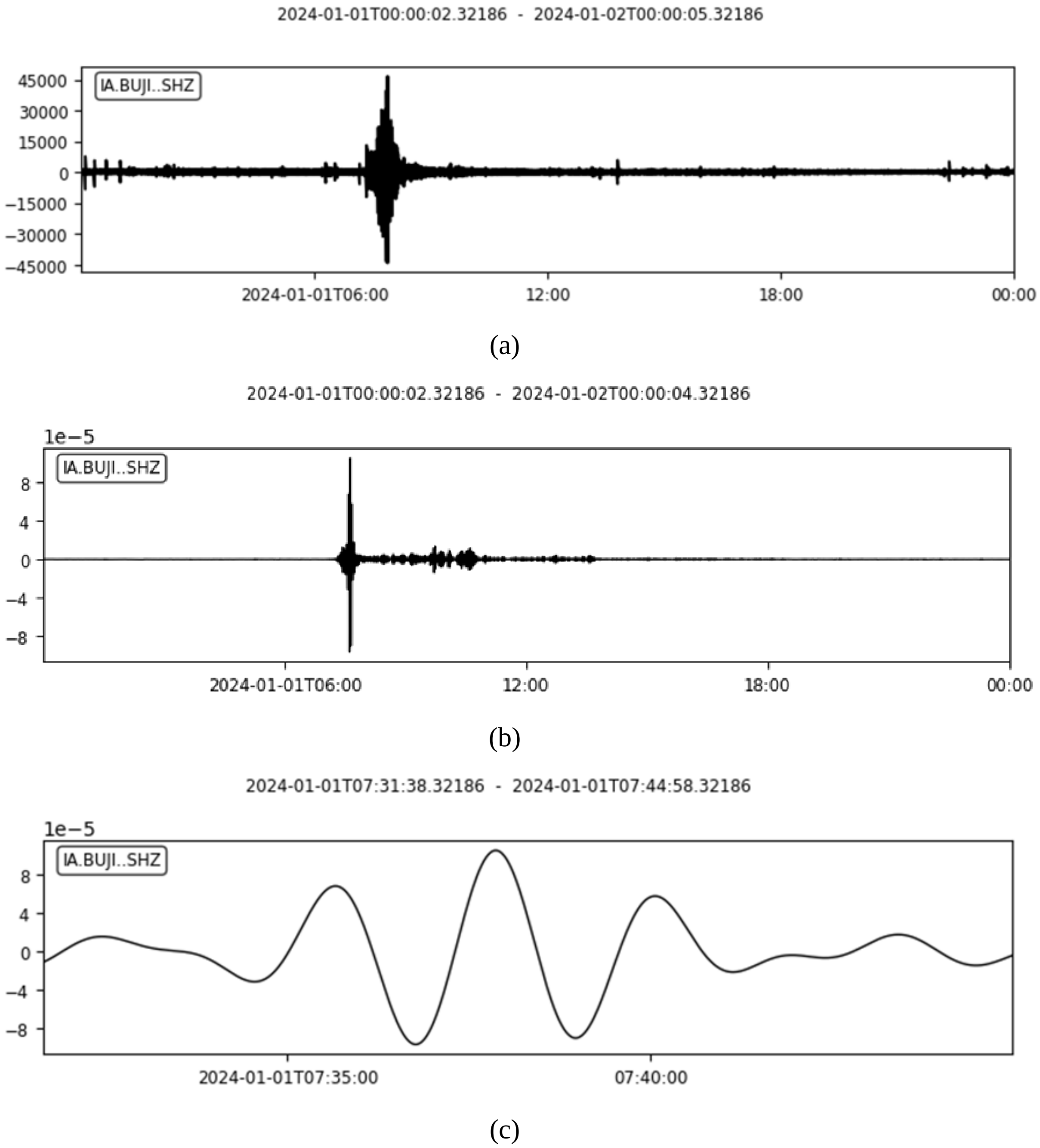


FIGURE 2. Block diagram of the research design.

In this study, Obspy [15-17] is a tool available in the Python library that is used to read seismometer recordings from the original signal, the signal is resampled to 1 Hz. A Butterworth bandpass filter is used to make the signal easier to interpret, which limits the signal frequency to 0.005 to 0.01 Hz. Deconvolution is used to restore the seismic waves to their original characteristics caused by the rock layers below the earth’s surface [18]. Since the signals obtained from BMKG are daily signals and the analysis in this study concentrates on the signals during earthquake events, signal truncation is performed so that the state of the seismometer can be ascertained from the seismic signals. Using the latitude and longitude information of the earthquake source, target station, and reference station, the seismic signal truncation process begins by calculating the distance between the earthquake source and the two stations [19].

As seen in FIGURE 3(a), the seismic signal must be processed from the original signal before calculating the coherence cross-spectral density value. Then, as seen in FIGURE 3(b), cut the signal. The resampled, filtered, and deconvolved seismic signal is the end result, as seen in FIGURE 3(c). The library from scipy.org is used in the cross-spectral density coherence method, converting it into the frequency domain using the Welch method [20] provided by scipy.org [21-23], comparing the target station signal and the reference station signal using cross-spectral density, and then calculating the cross-spectral density coherence value between the two signals, where the two signals have homogeneity if the cross-spectral density coherence value is close to 1 [24]. The cross-spectral density coherence value is a health indicator metric used to determine the health of a seismometer. The cross-spectral density coherence value that has been obtained will be given and analyzed by experts from BMKG.



(a)

(b)

(c)

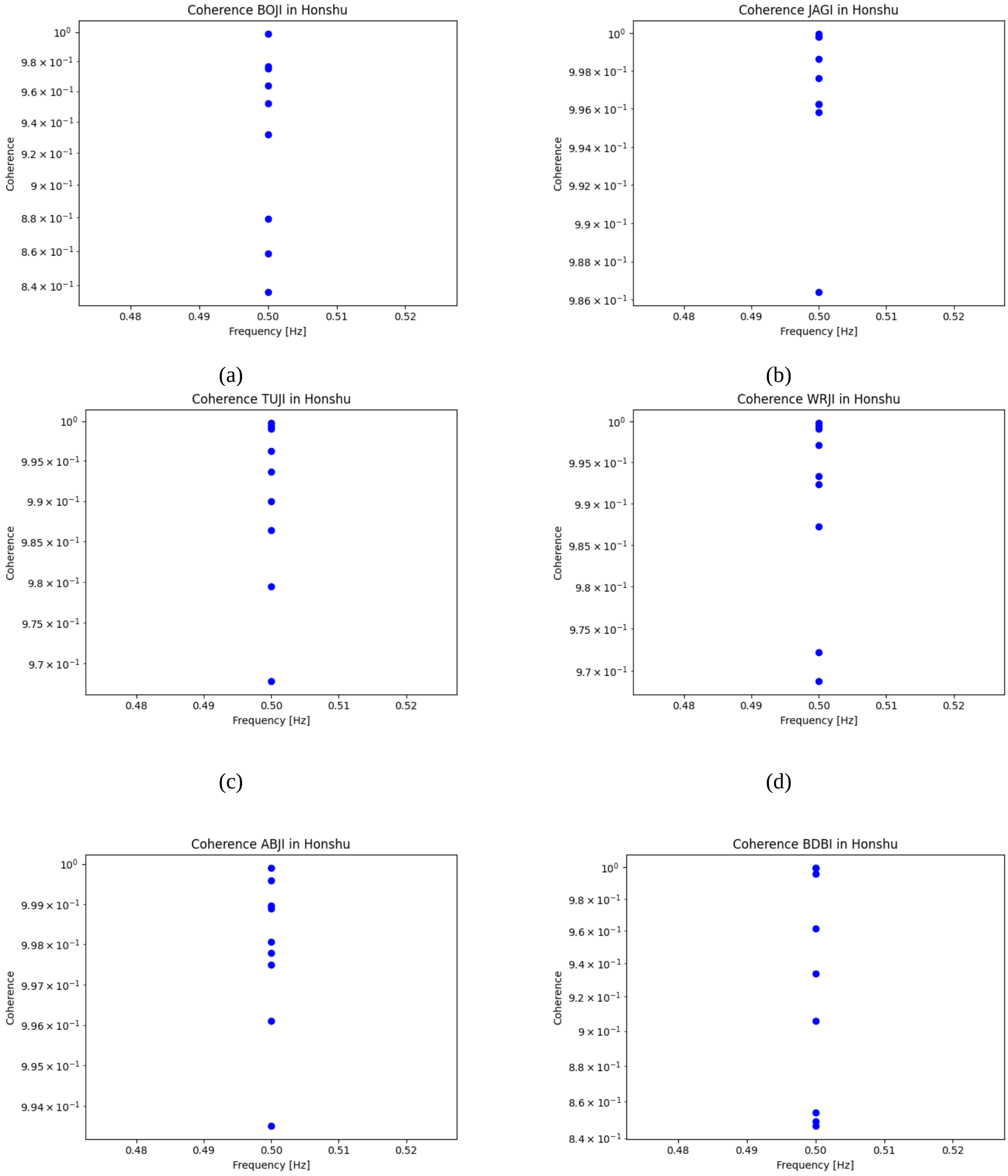
FIGURE 3. Signal processing at BUJI station. (a) Origin signal (b) Signal after resampling and deconvolved (c) Signal after truncation.

RESULT AND DISCUSSION

TABLE 1 shows the results of the analysis on 88 stations spread across the islands of Java and Bali. According to the expert analysis of the BMKG on the coherence value of the cross-spectral density at the station with three stations around it, 84 stations can be said to be healthy, and only four stations are unhealthy at the time of the earthquake in Honshu, Japan on January 1, 2024.

TABLE 1. Testing of 88 stations spread across the island of Java and Bali.

Station	Indicator	Station	Indicator
ABJI	1.00	KMMI	0.99
ACBM	0.56	KPJI	0.66
ACJM	0.81	KPJM	0.86
BBJI	0.72	KWJI	0.91
BBJM	0.86	LUJI	0.98
BDBI	0.93	NJBM	0.99
BKJI	0.82	NKBI	0.98
BLJI	0.99	PBJI	0.65
BMBNG	0.75	PCJI	0.88
BOJI	0.90	PCJM	0.77
BPMJM	0.99	PGJM	0.94
BTJI	0.98	PKJI	0.93
BUJI	0.94	PKJM	0.88
BWJI	0.97	PLJI	0.90
BYJI	0.99	PRJI	0.92
CBJI	0.89	PRLJI	0.98
CBJM	0.78	PSJM	0.79
CCJM	0.82	PTJI	0.94
CGJI	0.97	PWJI	0.97
CIJI	0.76	RTBI	0.95
CIJM	0.79	SADLY	0.92
CMJI	0.91	SBBM	0.98
CNJI	0.81	SBJI	0.95
CSJI	0.85	SCJI	0.75
CSJM	0.80	SCJM	0.87
CTJI	0.93	SEJI	0.82
CWJM	0.74	SKJI	0.77
DBJI	0.90	SMRI	0.87
GBJI	0.78	SPSJM	0.73
GGJM	0.97	SRBI	0.96
GRJI	0.91	SWJI	0.90
GTJI	0.80	SYJI	0.98
GUJM	0.84	TBJI	0.78
IGBI	0.97	TNGI	0.89
JAGI	1.00	TOJI	0.70
JBJI	0.88	TSJM	0.62
JBJM	0.95	TUJI	0.99
JCJI	0.87	UGM	0.97
JPJI	0.80	UWJI	0.77
JTJM	0.76	WLJI	0.88
JWJM	0.93	WOJI	0.96
KBBI	0.94	WRJI	0.99
KBJM	0.88	WSJM	0.81
KLJI	0.99	YOGI	0.96

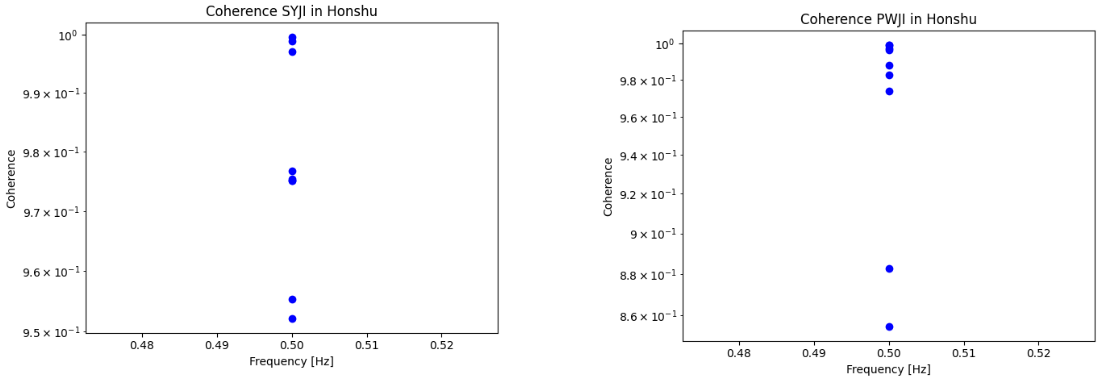


(a) (b)

(c) (d)

(e) (f)

FIGURE 4. Example of cross-spectral density coherence plots of stations in healthy condition. (a) BOJI, Sawit Boyolali Central Java (b) JAGI, Jajag Java (c) TUJI, Tumpakrejo Jember East Java (d) WRJI, Curahdami Bondowoso East Java (e) ABJI, Asem Bagus Java (f) BDBI, Badung Bali (g) SYJI, Sleman Yogyakarta (h) PWJI, Pagerwojo Java.



(g) (h)

FIGURE 4. (cont.) Example of cross-spectral density coherence plots of stations in healthy condition. (a) BOJI, Sawit Boyolali Central Java (b) JAGI, Jajag Java (c) TUJI, Tumpakrejo Jember East Java (d) WRJI, Curahdami Bondowoso East Java (e) ABJI, Asem Bagus Java (f) BDBI, Badung Bali (g) SYJI, Sleman Yogyakarta (h) PWJI, Pagerwojo Java.

FIGURE 4 shows that the seismometers at stations BOJI, JAGI, TUJI, WRJI, ABJI, BDBI, SYJI, and PWJI are in a healthy condition, as indicated by the cross-spectral density coherence value close to 1, which means that the target station has coherence with the surrounding reference stations [25]. The seismometer health indicators were in good health during the Japanese Honshu earthquake on January 1, 2024. Experts from BMKG have verified that the stations are stable and can record seismic signals accurately.

FIGURE 5 shows that the seismometers at ACBM, KPJI, PBJI and TSJM stations are in an unhealthy condition, as indicated by the cross-spectral density coherence values of 0.56 at ACBM station, 0.66 at KPJI station, 0.65 at PBJI station and 0.62 at TSJM station. The seismometer health index was unhealthy during the Japanese Honshu earthquake on January 1, 2024; experts from BMKG verified this. The TSJM station experienced seismometer mass not centered as well as the influence of ambient temperature and temperature. Recentering the mass and improving the seismometer insulation are the recommended improvements.

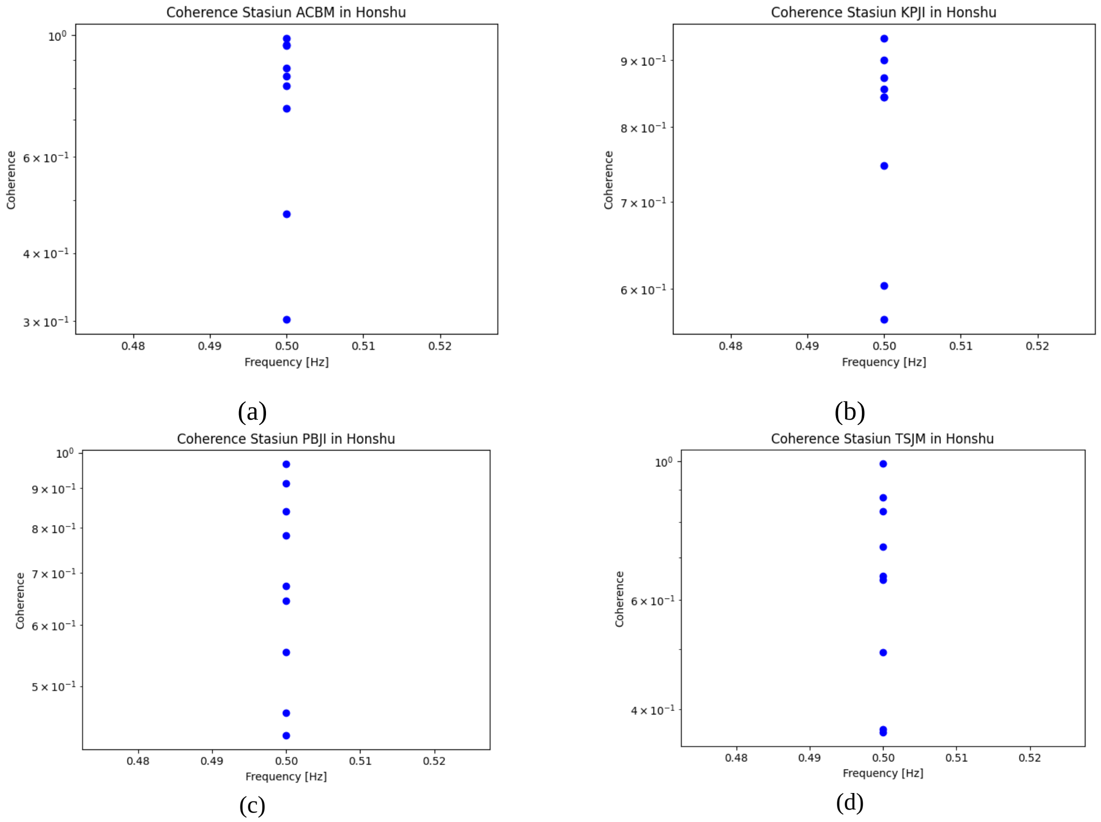


FIGURE 5. Cross-station spectral density coherence plots under unhealthy conditions. (a) ACBM, Ciparay Bandung West Java (b) KPJI, Karang Pucung Java (c) PBJI, Pasirjambu West Java (d) TSJM, Tanjungsiang West Java

CONCLUSION

We evaluate the health of broadband seismometers using coherence based on cross-spectral density, where the target station is evaluated with three neighboring reference stations [13]. The results of evaluating the health of broadband seismometers using this method show that the target stations tested in Indonesia are in good condition after the earthquake in Honshu, Japan. BMKG confirmed that 84 stations can be categorized as healthy stations. BMKG also confirmed that four stations were unhealthy. One of them is the TSJM station, which during the Honshu Japan earthquake on January 1, 2024, experienced a mass of seismometers not centered as well as the influence of ambient temperature and temperature. We found that the coherence cross-spectral density values of almost all tested stations were above 0.8, which means that the seismometers performed well during the Honshu, Japan, earthquake on January 1, 2024. Seismometers can be checked without having to go to the station where they are deployed once their condition - whether healthy or unhealthy - is determined by seismic signal analysis. This saves time and repair costs. More earthquake events should be used in this study to compare the performance of seismometers more accurately. In addition, using machine learning or deep learning approaches can improve this research and by using more diverse indicators for seismometer health.

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