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Integrated seismo-geodetic observatory network for monitoring the Lembang Fault, West Java, Indonesia

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Key Points:

- A new seismo-geodetic observatory network has been developed for active fault monitoring and mitigation of the Lembang Fault near the metropolitan area of Bandung.
- A notable compression strain rate along the Lembang Fault indicates a significant accumulation of tectonic stress.
- A negative polarity observed on the radial component suggests a low-velocity zone in the crust beneath the Lembang Fault.

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Abstract: The Lembang Fault is a major geological feature in West Java that borders the northern edge of Bandung (one of Indonesia's largest cities). It lies just south of the active Tangkuban Perahu Volcano, exhibiting clear geomorphic signs of recent activity, and has been scientifically confirmed as active through geological and geophysical studies. In this work, we describe an Integrated along the Lembang Fault, which can be used for geodynamic research in Indonesia. We discuss the design of a seismic and Global Navigation Satellite System (GNSS) array sensor network for continuous monitoring, and report the status of monitoring stations that periodically collect highly accurate, continuous seismographic and GNSS readings, transmitting these data to a central server in Bandung for post-processing. Solutions from the array data are used to provide precise measurements of the deformation of the Earth's surface over large distances, allowing for spatio-temporal tracking of tectonic movement, and resulting in a better understanding of seismic events in the region. In this study, our investigation revealed a significant compression rate of an estimated 13 microstrain/yr along the Lembang Fault, whereas the strain rate is much smaller farther south of the fault. This study presents the design of a seismo-geodetic observatory network that can be implemented in earthquake-prone regions for mitigation purposes, with particular utility for studying other active faults that also traverse populated areas in Indonesia.

Keywords: Lembang Fault; seismo-geodetic observatory; earthquake; disaster risk reduction

1. Introduction

The Lembang Fault lies on the north side of the Bandung metropolitan area, which is home to ~8.7 million people across Bandung City, Bandung Regency, West Bandung Regency, Cimahi City and Sumedang Regency (Central Statistic Agency, 2021). Based on geological, geodetic, and geophysical studies, the Lembang Fault is known as an active fault with a length of 29 km and a slip rate of 4.7 mm/yr, with the potential for earthquakes of magnitudes M_w 6.6–7.0 that could generate a ground shaking of more than 0.3 *g* (Hussain et al., 2023). Somantri et al. (2023) have suggested that the intensity of the earthquakes occurring here could reach a Modified Mercalli Intensity (MMI) of VIII; this would have a significant impact on six cities/districts in particular: Bandung, Cimahi, the Bandung Regency, the West Bandung (*Bandung Barat*) Regency, the Subang Regency and the Sumedang Regency, as shown in Figure 1. Therefore, it is important

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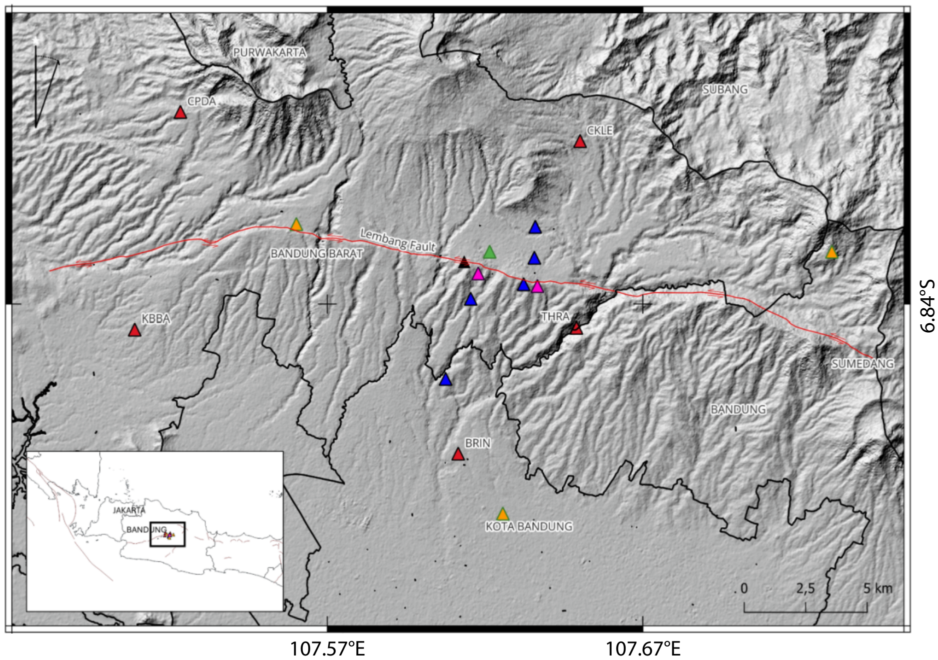

Figure 1. Landscape of the Lembang Fault and the seismo-geodetic site locations used in this study (red triangles). Continuous GNSS sites of ITB and BIG are shown by blue and green triangles respectively. Existing collocated seismo-geodetic stations of the CVGHM are indicated by orange triangles, and their two seismic stations as dark orange triangles; the BMKG seismometers are indicated by black triangles and the existing. Lembang Fault derived from PuSGeN 2017.

to make efforts to strengthen earthquake risk reduction in this area due to the Lembang Fault's active state.

The occurrence of an earthquake in the Lembang Fault could be catastrophic, potentially exposing 1.9 to 2.7 million people to high levels of ground motion (>0.3 *g*) in the event of an earthquake of M_w 6.6–7.0 (Hussain et al., 2023). Previous events illustrate the extent of the hazard. For example, a M_w 3.3 earthquake in 28 August, 2011, which occurred due to the Lembang Fault's activity, damaged around 385 houses in the Lembang Regency (Meilano et al., 2012). Additionally, the M_w 6.8 Tasikmalaya intraslab earthquake on September 2, 2009, the epicenter of which was more than 150 km to the south of the Bandung Basin (Gunawan et al., 2019), destroyed about 40 houses in Lembang along with hundreds of houses in the South Bandung area.

To support efforts being made in earthquake risk reduction in this area, we have developed the Lembang Near-Fault Observatory, designed to study and monitor geophysical, geological, and geodetic signs of earthquakes based on activity in the Lembang Fault. The observatory consists of active fault monitoring equipment such as seismometers and GNSS (Global Navigation Satellite System). Data gathered by this network will improve the accuracy of earthquake risk assessment for the city of Bandung and the surrounding population areas. The observatory will also contribute to public awareness about the risks of earthquake disasters, while strengthening earthquake research and education in this region.

Similar near-fault observatories worldwide, such as those in Japan (e.g., Aoi et al., 2020), the SLO KARST Near Fault Observatory in SW Slovenia (Šebela et al., 2023), and the Alto Tiberina near fault observatory and the Near Fault Observatory (NFOs) in Europe (Chiaraluce et al., 2014, 2022), have proven effective in capturing seismic and geodetic signals. A dedicated GPS array network was developed in Sumatra island, namely SUGAR, consisting of Geodetic observation not integrated with seismic observation (e.g., McLoughlin et al., 2011). The newly developed observatory network described in this paper is the first integrated seismo-geodetic observatory network on an active fault near an urban area in Java Island, Indonesia.

2. Tectonic Setting

The Lembang Fault is an active fault with a remarkable topographic expression, situated 10 km north of Bandung. The fault has a north-facing fault scarp, ranging in height from 10–450 m. Large-scale geomorphic mapping and dating of offset volcanic material indicate that the fault is separated into two sections: an older eastern section, which was activated some 104 kyr, and a younger western section, which became active around 24 kyr (Nossin et al., 1996). The Lembang Fault is thought to have initially formed from a large-scale sector collapse of the relic Sunda Volcano due to rapid depressurization of the volcano's magma chamber (Van Bemmelen, 1949). The segmentation of the fault is seen in its topographic expression as the eastern section, which has a much larger (200–400 m) scarp, while the western section has a smaller scarp (10–150 m) that is still very steep and pronounced.

Previous studies have reported obvious morphological features, along with several records of recent small seismicity and the near-past behavior of the Lembang Fault (e.g., Tjia 1968, Satriyo et al., 2024). Earlier studies have also described the fault's initial formation and variations in its movement (Van Bemmelen, 1949; Nossin et al., 1996). Paleoseismological studies of the Lembang fault in a sag-pond deposit and three trenching locations have revealed at least two plausible historical earthquakes in the 15th century and

2300-60 BCE, characterized by observable displacement in the stratigraphy (Yulianto et al., 2011; Daryono et al., 2019). The geometry and lateral slip of the Lembang Fault suggests that it may be capable of producing earthquakes of magnitudes close to 6.6 to 7.0 (Meilano et al, 2012; Hussain et al., 2023).

3. Present-Day Deformation

The study of tectonic deformation in Java Island using GNSS, as described by Hanifa et al. (2014), was conducted from 1989 to 1993 by Tregoning et al. (1994) to estimate convergence along the Java Trench. Their studies were conducted by installing the BAKO site on Java Island, XMIS on Christmas Island, and COCO on Coco Island. GNSS campaigns began in West Java in the late 1990s to study the local deformation around the main faults nearby; namely, the Cimandiri, Lembang, and Baribis Faults (Abidin et al., 2009; Meilano et al., 2012). Most of these GNSS observations were made in campaign GNSS measurements.

The installation of continuous GNSS (cGNSS) is named as the Indonesian Continuously Operating Reference Stations (Ina-CORS). It was launched at the end of 2007 and was installed and managed by the Geospatial Information Agency (BIG) (Subarya et al., 2010). As of 2023, Ina-CORS consists of more than 100 stations, and has been used in a number of geodynamic research studies (Gunawan et al., 2016, 2022a, 2022b, 2023a; Patimah et al., 2022). A continuous station has been installed near the Lembang Fault zone, named CLBG. Abidin et al. (2009) reported a horizontal displacement of 1–2 cm/yr or less in the Lembang Fault. A further study by Meilano et al. (2012) used GNSS campaign data measured once a year for 3–5 days from 2006 to 2011, as well as continuous GNSS data at four locations. The results of their study suggest the presence of three vertical depth ranges: the shallow creeping area of 0–3 km, the seismogenic area of ~3–15 km, and the deep slip zone (>15 km). The best estimates for shallow and deep creeping rates is 6 mm/yr. Meilano et al. (2012) argued that the estimated model could not explain deformation at all locations due to the poor quality of the campaign observations.

The Global Geophysics Research Group of the Bandung Institute of Technology (ITB) began reinstalling cGNSS stations around the Lembang Fault, beginning in 2019. Currently, five cGNSS stations have been installed around the Lembang Fault along a perpendicular line in the middle of the Lembang Fault, as shown in Figure 1. To gain a better understanding of the tectonic deformation and geodynamic activity around the Lembang Fault, we installed four additional cGNSS stations along the Lembang Fault in 2022 to complement previously installed observations. The data from the latest existing network, which is also equipped with additional seismic stations, could be used to understand the present-day deformation of the Lembang Fault.

4. Design of the Lembang Near-Fault Observatory

4.1 Collocated Seismo-Geodetic Site Selection and Set-Up

The collocation of continuous GNSS and seismometer data has been used globally for earthquake monitoring, research and early warning systems (Geng et al., 2013; Chiaraluce et al., 2014). Our seismic network is specially designed for monitoring earthquake activity at the Lembang Fault, research and initial study on the possible application of a seismo-geodetic network for early warning. Seismometers were installed with their frequencies corresponding to the wide range of magnitudes of the seismic activity of the Lembang Fault, covering the entire fault area (approximately 29 km long). In addition to the seismometers, cGNSS observation posts are also in place. This combined seismo-geodetic observatory network has been named the Lembang Near-Fault Observatory (LFO). Data from the seismometers and cGNSS are sent from the stations to a server at the BRIN Cisitu office in Bandung. This design is expected to become a prototype for near-fault observatory networks, focused on faults located adjacent to urban areas. The LFO is also planned as an earthquake hazard education center for the surrounding communities. Four collocated seismo-geodetic sites were installed in 2022 as part of the LFO in collaboration with Institut Teknologi Bandung (ITB) and Earth Observatory of Singapore (EOS), and another geodetic site (CKLE) was also installed at the end of 2024 (Figure 2). The process of sending data by telemetry to the LFO system at the BRIN Cisitu office is carried out continuously.

Site location criteria were chosen based on with proximity to the

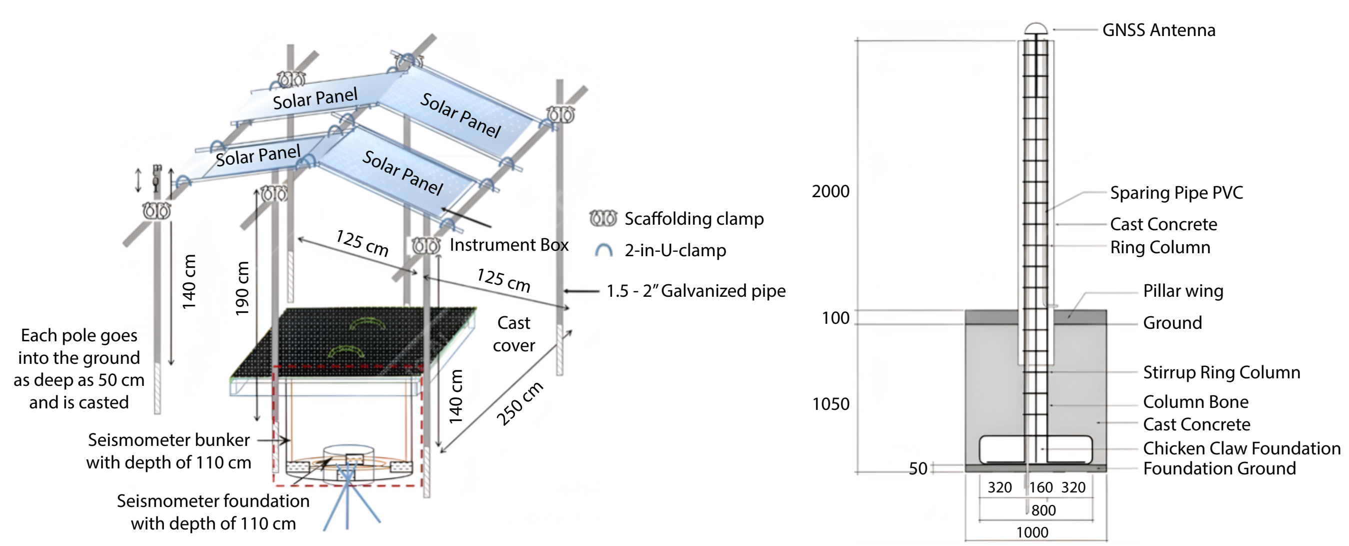

Figure 2. Blueprint of the structure of (left) the seismic station; (right) GNSS station.

Lembang Fault; with a focus on positioning new sites in areas not yet covered by existing seismo-geodetic networks established by the Agency for Meteorology, Climatology, and Geophysics of Indonesia (BMKG), ITB and the Center for Volcanology and Geological Hazard Mitigation (CVGHM) as shown in Figure 1, while also considering land availability owned by local government authorities. The latter was chosen for safety, security, sustainability and building collaboration for earthquake preparedness. The seismometer was placed in a quiet area, whereas the GNSS sites require open views of the sky. Another factor taken into account was the availability of internet signals at the site location, making the telemetry process much easier. Based on these criteria, five sites were selected, as shown by the red triangles in Figure 1, with their locations shown in Table 1, and their placements are shown in Figure 2.

Table 1. Coordinate of the new establish seismo-geodetic network of Lembang Near-Fault Observatory (LFO).

Name	Longitude (°)	Latitude (°)
BRIN	107.612	−6.882
KBBA	107.511	−6.844
THRA	107.648	−6.843
CKLE	107.649	−6.787
CPDA	107.526	−6.778

Each seismograph sensor records all detected seismic vibrations (Abdullah et al., 2021; Rubiyana and Nurcahya, 2021; Simanjuntak et al., 2023). A seismic network consisting of at least four stations is required to determine the location and magnitude of an earthquake. Broadband seismic networks are usually built as part of a global network (Lay et al., 2002). The broadband seismometer is installed at a frequency that can receive all seismic vibrations worldwide, and register high-magnitude vibrations while remaining insensitive to low-magnitude vibrations. Local seismic networks, which may also be part of a global network, are better able to record vibrations from local activities (Kishkina et al., 2012). Seismic networks designed to monitor a particular object are also commonly built to monitor volcanoes (Castellano et al., 2002; Budi-Santoso et al., 2013; Gunawan et al., 2017). Because volcanic vibrations often have a low magnitude, a seismometer designed to monitor the low frequencies of volcanoes was installed to record local vibrations (volcanic/tectonic/tremor). As for the observations of certain faults, in addition to aftershock observations from the global network, it is also common to utilize temporary seismographs, usually installed for a few months to several years (Afnimar et al., 2015). Two permanent networks in Italy are examples of such specialized networks used for specific fault observations, both of which cover large areas of a very active fault zone (Chiaraluce et al., 2014; Adinolfi et al., 2019).

The main elements of a seismic station consist of sensors, data loggers, telemetry antennas, and solar panels as a source of electric power. The Research Center for Geological Disaster, for example, utilizes four Guralp broadband seismograph sensors with a flat response to velocity from 30 s to 50 Hz. Figure 2 shows the construction blueprints for this seismic station.

The primary components for a GNSS installation consist of a GNSS choke ring antenna and receiver. The design of the GNSS station monumentation and installation is adjusted from the Indonesian National Standards (2022) for CORS station installation and other feasible designs, according to location and circumstances (SNI 7964:2022). The GNSS consists of a roof pin attached to the top with a Trimble GNSS, and a concrete pillar in the form of a monument. Both components are steady-state, and collocated with seismic data.

The installed instruments can carry out daily data acquisition, consisting of collocated seismo-geodetic site selection, and set-up for the THRA site (located in the deer-breeding area of the Djuanda Forest Botanical Park, Bandung), the KBBA site (West Bandung Regency local government office), the CPDA site (Cipada village and the Cipada forested area, West Bandung Regency), and the rooftop of the BRIN office in Cisitu, Bandung City, as shown in Figure 3.

4.2 Data Communication

A telemetry system is used for data retrieval from remote areas that are difficult to reach. Through communication protocols based on GPRS, GSM, or radios, data obtained remotely can be processed by a computer and displayed directly on the web (Dutono and Santoso, 2022). By placing a sensor or transducer at the location of the measured object, the measurement data can be retrieved remotely using various data communication methods and media for data communication. In this study, the GPRS/3G/4G/5G network was used as a medium for data communication, and a GSM modem used to transmit data to a database server, which is later processed for display on the web (Othman et al., 2023).

Advances in telemetry technology have made it possible to utilize this technology in the system activities of the LFO, and quickly distribute the resulting data/information to users. Telemetry technology facilitates continuous monitoring, which is essential for collecting consistent baseline data over extended periods. Furthermore, it enables the remote acquisition of measurement data from distant or inaccessible locations, thereby enhancing operational efficiency and minimizing the need for direct field intervention.

4.3 Server and Archiving System

The archive server performs data management that controls the archiving, retrieval, and distribution of stored data from each site. The main functions performed by the archive server include: (1) receiving data acquired from the seismometers and receiver GNSS systems; (2) archiving data to the storage subsystem; (3) routing data to views; (4) archiving updates; and (5) handling and retrieving requests from other registered clients. The archival database consists of data obtained from telemetry results which are stored on the server. To ensure data integrity, the archive database is configured to include a mirroring feature that allows data to be automatically duplicated on a separate system disk of the archive server.

5. Results and Discussion

5.1 Data Acquisition, Data Communication and Archiving System

In this research, a comprehensive data acquisition system was

Figure 3. Collocated seismo-geodetic sites for the Lembang Fault Network; (a) KBBA site, (b) CPDA site, (c) THRA site, and (d) BRIN site.

designed, one that seamlessly integrates multiple sensors such as seismometers and geodetic instruments, to capture precise seismic and ground deformation measurements. This system enables the observatory to obtain a comprehensive understanding of the dynamic behavior of the near-fault region. Additionally, a robust data communication framework was established to facilitate real-time transmission of collected data to the observatory's data server. The system enables prompt access to the data for further processing and analysis, empowering researchers to monitor and evaluate seismic and geodetic events as they unfold.

A reliable archiving system was implemented to ensure effective data management and long-term preservation. By archiving the data, the Lembang Near-Fault Observatory developed in this study contributes to the cumulative knowledge base of seismology and geodesy, facilitating further comparisons and studies of events.

The hierarchical structure of the data directory within the data server system provides a visual representation of how data is organized and stored, highlighting the relationships between different directory levels. Further subdivisions can be observed within each subdirectory, representing more specific data subsets. These subdivisions, based on criteria such as time or location, highlight the nested structure of the directories, with each level providing more granular organization and categorization of the data. Data recording time was divided into the first per 30 seconds (2020-a) and the second GNSS per 1 second (2020-c).

5.2 Seismic Network Observation and Data

Regional and teleseismic events have been recorded at the Lembang Fault Seismic Network, for example the Cianjur Earthquake on November 21, 2022 (*M*5.6), the Kertasari Earthquake on September 18, 2024 (*M*4.9), and the Turkey Earthquake on February 6, 2023 (*M*7.8) as shown in Figure 4. The data recorded by this network can help researchers better understand seismic activities in the region, and assist in earthquake disaster mitigation.

In addition to monitoring seismic activity, we utilized the teleseismic events recorded at our stations, particularly at THRA and KBBA, for applying a receiver function (RF) technique to estimate the subsurface structure information near the receiver seismic stations. We excluded processing teleseismic data from the CPDA station because its horizontal and vertical components utilize different types of sensors. We used teleseismic events at epicentral distances of 30–90°, $M \geq 5.5$ in the period from May 2022 to December 2023 (Figure 5a). It appears that the source of the teleseismic events comes largely from the subduction zones around Japan and the Mariana Trench, which is in the back-azimuth (BAZ) of around 30–60°, and from the subduction zones around the New Britain, Solomon, and Tonga Islands (BAZ of 90–120°). For the scope of this study, we test the recorded waveform by calculating the receiver function waveform, and leave the inversion for further studies. The teleseismic data were processed following the steps performed by Nurfiani et al. (2021). We rotated the horizontal components of teleseismic event records to the radial and tangential components. We cut the data from 10 s before and 80 s after the first P wave arrival. We then computed the radial receiver functions by deconvolving the vertical component from the radial component with an iterative time-domain deconvolution method (Ligorría and Ammon, 1999), with a Gaussian filter parameter of 2.5 corresponding to a low-pass filter with a corner frequency of about 1.2 Hz. We removed the receiver functions that show abnormal waveforms, which could have various causes, such as low signal-to-noise ratio.

Figure 5b shows the radial and tangential components of RF waveforms at THRA and KBBA stations. THRA shows more RF waveforms than KBBA, which could be because THRA is located in a quiet forest park, where there is less noise compared to the KBBA site location, which is located in an open space at the local government office. The impulsive signal at time 0, which is more clearly seen at the radial components, corresponds to the direct

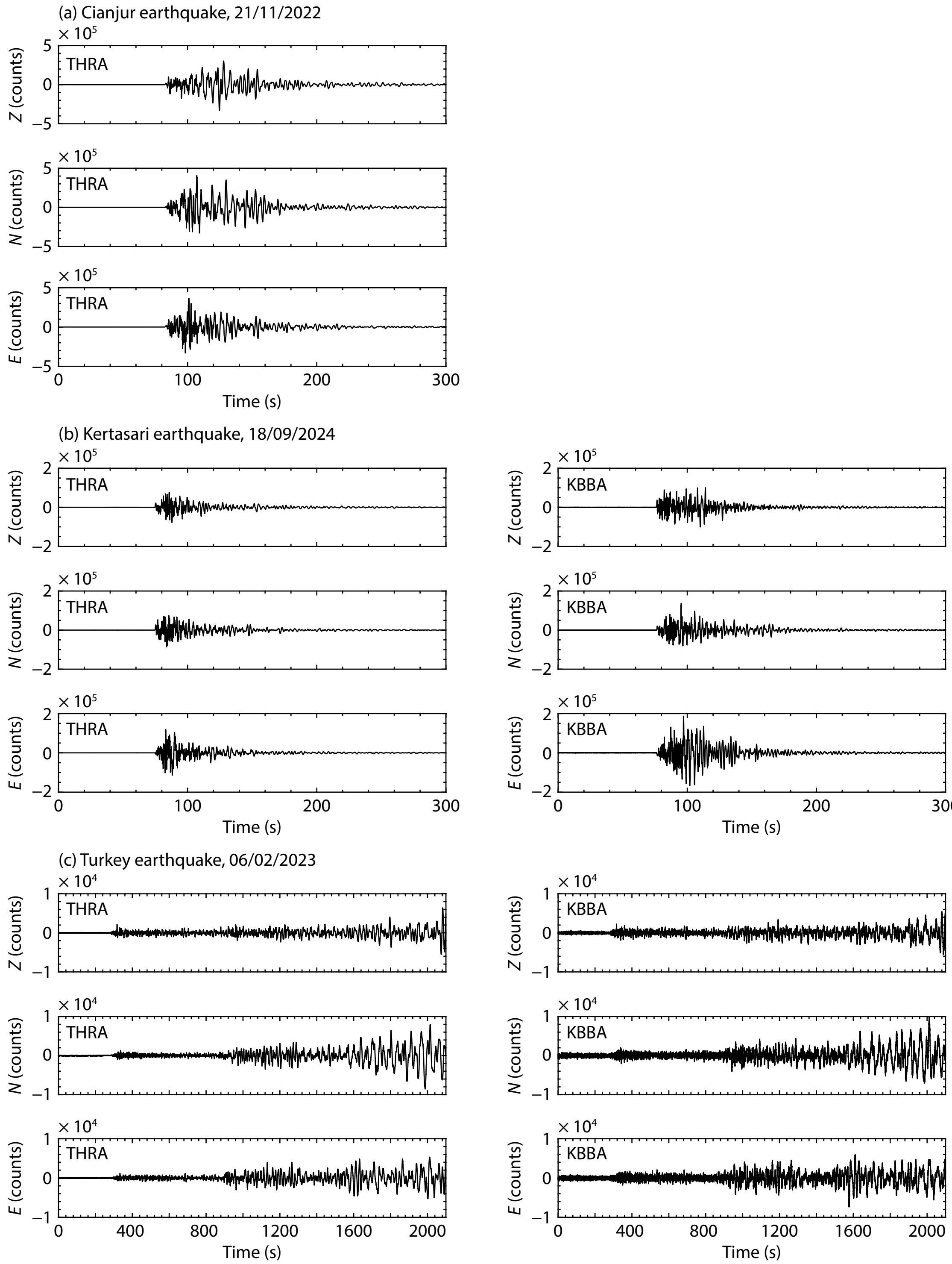

Figure 4. (a) Cianjur earthquake on 21 November 2022 (*M*5.6); (b) Kertasari earthquake on 18 September 2024 (*M*4.9); and (c) Turkey earthquake 2023 (*M*7.8) detected by two seismic stations at LFO site.

P-wave arrival. At the THRA radial component, the RF waveforms coming from the first quadrant (back-azimuth [BAZ] of 0–90°) and second quadrant (BAZ of 90–180°) are notably different. At the first quadrant, following the direct P-wave arrival, a consistent negative polarity is observed at <2 s in the BAZ of 20–50°, occurring before the P-to-S converted phase from Moho discontinuity (positive signals at ~3–4 s). At the second quadrant, the negative polarity is somewhat shifted to ~3 s in the BAZ of 90–120°. In addition, the THRA tangential component of RF shows the emergence of seismic energy. Meanwhile, for the current observation period, KBBA contains fewer RF waveforms, and we suggest extending the observation to collect more seismic events or data.

The negative polarity at the THRA radial component indicates a low-velocity zone (LVZ) within the crust beneath THRA. A similar pattern of consistent negative polarity has also been observed in previous studies of the Cimandiri Fault (Ariyanto et al., 2023) the Tangkuban Parahu Volcano (Syafawi et al., 2023), and West Java region (Anggono et al., 2020) at a depth of 20 to 30 km. Based on ambient noise tomography (ANT), Syaifuddin et al. (2025) suggested that the low-velocity anomaly around the Lembang Fault could be caused by fluid-filled fractures. Similarly, Ariyanto et al. (2023) attributed the LVZ to the presence of the Cimandiri Fault plane, which typically exhibits lower density that leads to a decrease in seismic wave velocity. However, in this study, we have not yet performed receiver function inversion for obtaining subsurface velocity structure to better constrain the depth and characteristics of this anomaly.

5.3 Continuous GNSS Data

The GNSS time series from the Tahura site (THRA), Cipada site (CPDA) and West Bandung Regency site (KBBA) were processed using GipsyX (Bertiger et al., 2020; Gunawan et al., 2023b). A precise positioning method was employed to estimate the daily solutions of the GNSS data. This analysis was conducted using a fiducial-free approach with five iterations. We used the Jet Propulsion Laboratory's reanalysis product of the final set of the International GNSS Service 2014 (IGS14) orbit and clock products. We then set the elevation angle cut-off at 15 degrees, and utilized ocean-loading parameters from the Onsala Space Observatory (http://holt.oso.chalmers.se/loading/), using the GOT4.8 model.

In order to show the deformation data that represents current understanding of tectonic dynamics along the Lembang Fault, the data was transformed into a Sundaland block reference frame, following Simons et al. (2007). The pole rotation parameters used to calculate the daily solutions from ITRF2000 to the Sundaland

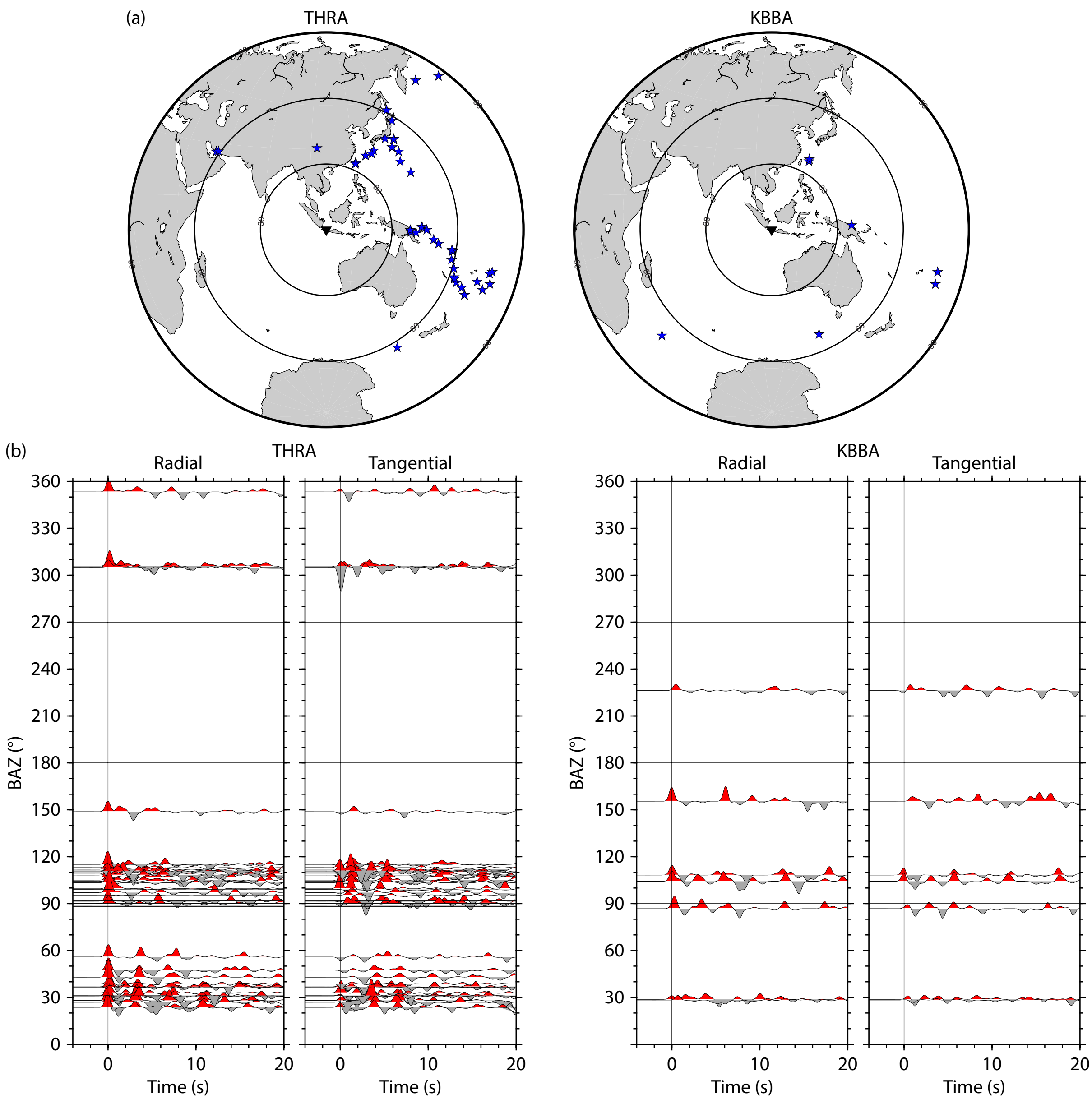

Figure 5. (a) Distribution of the teleseismic events ($M_w \geq 5.5$) used in obtaining receiver function waveforms at THRA and KBBA stations as plotted in (b). The black inverted triangle shows the location of the Lembang Fault area. (b) Radial and tangential component receiver function (RF) waveforms as a function of back azimuth (BAZ) for the two stations. The time zero corresponds to the direct P-wave arrival.

block were 49.0°N, −94.2°E, and 0.336 °/Ma. Thus, our daily solutions from ITRF2014 to ITRF2000 were transformed prior to calculating the Sundaland block motion. Generally, the uncertainties in the horizontal components are approximately 2 mm, whereas those in the vertical components are around 6 mm. Figure 6 shows the time series at the CPDA and KBBA sites in the Sundaland block reference frame.

5.4 Strain Rate Analysis

The daily solutions from each GNSS site provide insights into the present-day tectonic processes occurring along the Lembang Fault. By combining these data with the available GNSS data maintained by the Global Geophysics Research Group at the Bandung Institute of Technology (blue triangles in Figure 1), we calculated the strain rate along the Lembang Fault. Our analysis, using a triangle of three GNSS stations, revealed a significant compression rate of 13 microstrain/yr estimated along the fault (Figure 7). Further south of the Lembang Fault, the strain rate is much lower. These findings clearly indicate ongoing deformation along the Lembang Fault.

Investigating the fault-locking depth and slip rate of the Lembang Fault based on long-term data is also feasible for mitigating risks in the Bandung metropolitan area. By combining the GNSS data with InSAR, Hussain et al. (2023) suggested that the slip rate of the Lembang Fault is 4.7 mm/yr. Furthermore, the integrated use of GNSS and InSAR data can also be applied for slope monitoring (Maulana et al., 2023). This approach has even been utilized in tunnel construction projects in Indonesia (Aldiamar et al., 2021). Hence our research on integrating seismo-geodetic networks can serve as a benchmark not only for disaster preparedness, but also for construction and other applications in Indonesia where such data integration is needed. We intend to continue expanding this monitoring network along the Lembang Fault in the years to come.

5.5 Integration of Seismo-Geodetic Observation Analysis

This new observation network integrates both seismological and geodetic instrumentation, to understand and monitor the active

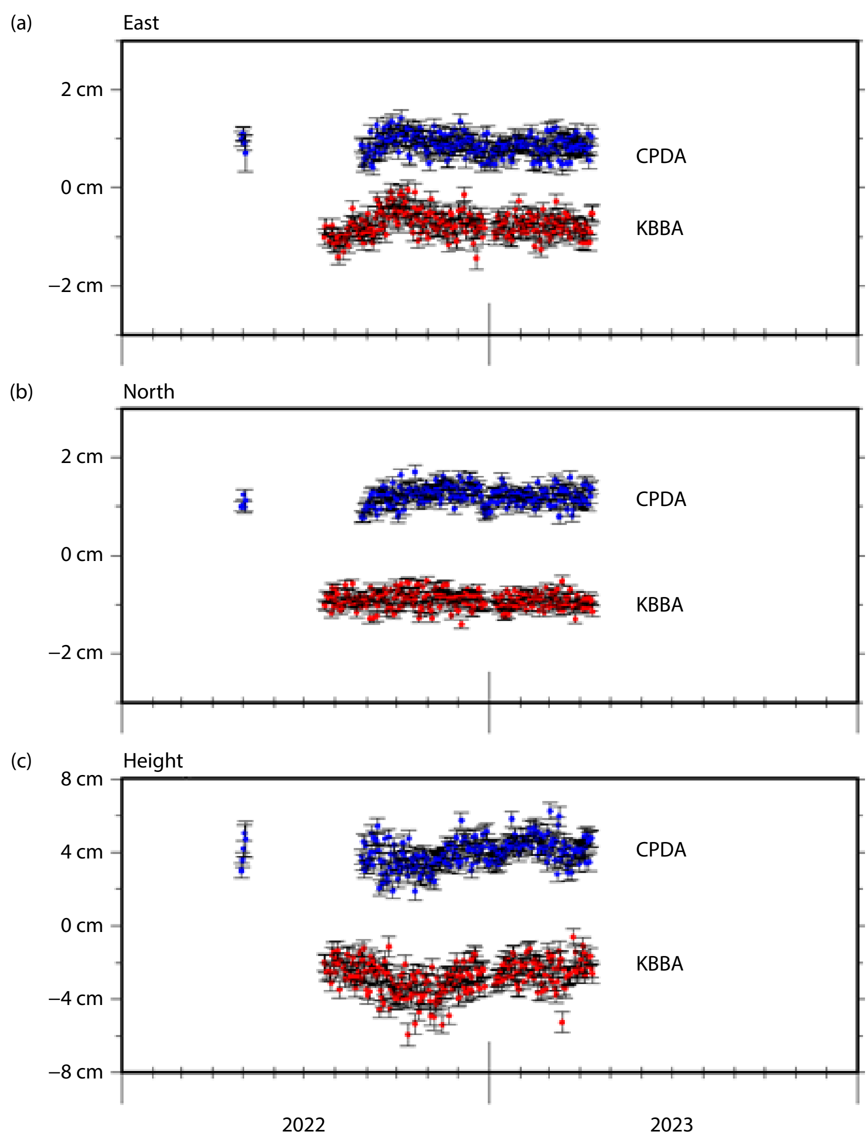

Figure 6. GNSS time series at the CPDA and KBBA sites in the Sundaland block reference frame.

Lembang Fault. We provide preliminary results from receiver function and strain rate analyses. The complexity observed in receiver function tangential components may provide insights into crustal structures that correlate with geodetic measurements of strain. While receiver functions and strain rates measure different physical properties at different time scales, their spatial patterns across tectonic regions may reveal important connections between past deformation preserved in crustal structure and ongoing tectonic processes.

Tangential component energy in receiver functions primarily indicates the presence of anisotropy or dipping interfaces, which develop through long-term deformation processes. These structural complexities serve as a record of accumulated strain throughout the geological history of a region. Concurrently, GPS-derived contemporary strain rates measure the current velocity field and active deformation along the Lembang Fault. The strain-rate along active faults has been also proposed by Gunawan and Widiyantoro (2019), who indicate a higher strain rate along active faults in Java, such as along the Lembang Fault, Cimandiri Fault, Cipamingkis Fault, and Java Back-arc Thrust Zone in Java. The potential correlation between these measurements offers a framework for understanding the continuity of deformation processes across different timescales. The Lembang Fault displays complexity in tangential receiver functions, so we might expect relatively high strain rates. This correlation could suggest that zones of structural complexity will align with the continued deformation.

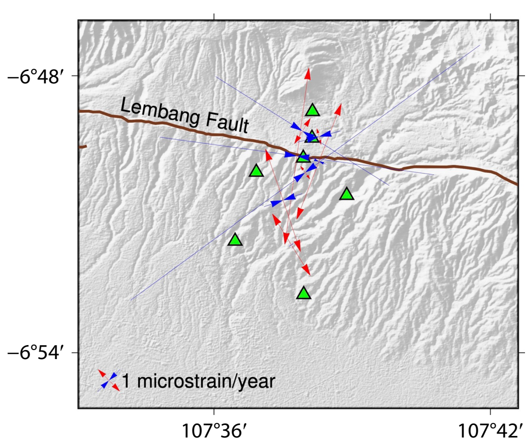

Figure 7. Strain rate analysis along the Lembang Fault. The solid brown line indicates the trace of the Lembang Fault. The green triangles remark the locations of GNSS stations used in the analysis.

6. Conclusion

The initiative of the integrated seismo-geodetic Lembang Near-Fault Observatory in the Bandung metropolitan area began in 2022 as a collaboration between Indonesia (BRIN and ITB) and Singapore (EOS). This consisted of four stations using a telemetry system to continuously monitor and research in detail the seismic activity of the Lembang Fault and its surrounding area, as well as the fault's crustal deformation rate and characteristics. This network is the first integrated seismic-geodetic network system to continuously observe an active fault near an urban area in Indonesia using a telemetry system.

To validate the data quality, we analyzed the cGNSS and seismic data at the THRA station in the early phases. The cGNSS data recording times are per 30 seconds and per 1 second. The initial phase of cGNSS data was processed for the first three months at the THRA site, which indicated good data recording. A minimum of two years of data will be needed to enable further analysis of the spatio-temporal variation slip-rate of the Lembang Fault. Meanwhile, during the period from May 2022 to December 2023, there were 218 and 181 teleseismic events recorded at THRA and KBBA, respectively, only 48 and 7 RF waveforms of from which passed a quality check, respectively. This quality check involved manually removing the receiver functions that showed abnormal waveforms, which could have a number of causes, such as a low signal-to-noise ratio. The more RF waveforms that are included for RF inversion, the better the results will be. Hence, the next step involving RF inversion is left for the future work of collecting more teleseismic events that are recorded at the seismic station. The RF inversion results will provide the subsurface velocity structure beneath the station, as well as the depth of the possible low shear velocity.

Establishing this network on land owned by the local government has also created a wider collaboration between the local government, the West Bandung Regency Management Authority, the villages involved, and Taman Hutan Raya Djuanda. This collaboration has enabled knowledge sharing between researchers and the local government and communities. Collaboration with other institutions that have installed seismo-geodetic networks is ongoing. Further data analyses and scientific communication from this observatory are expected to increase in the coming years, helping to build earthquake resilience in the Bandung metropolitan area.

Credit Author Statement

NRH, EY, AT, DA, LH, MH, RS, AGS, DH, DN, IH, EG, SW, AFS developed the conceptual framework. NRH, DA, EG, LH, MH, DN, AFS, AGS, RS, EY, PNR, TA wrote the manuscript. NRH, EG, DA, IH, conducted the GNSS data processing and analysis. LH, MH, DH, DN, ANA conducted the seismic data processing and analysis. NRH, DN, TA, FM, PNR, EG, AFS conducted the integrated seismo-geodetic analysis. AGS, RS, DH, IH, AM, WHN, BS, AFS set up the telemetry process, data communication and data storage. NRH, DA, YS, JA, AMR, DN, AFS, DH, IH, JT, NED, RA, MH, AGS, RS, AP worked on the installation of seismic and GNSS stations. AFS, DN, PNR, WHN, QZ, RI, CP generated the figures, and AFS conducted the drone acquisition. All authors conducted the field work and data acquisition, participated in weekly discussions, interpreted the results, and reviewed the manuscript. All authors have read and agreed to the published version of this manuscript.

Declaration of Competing Interest

The authors declare that they had no conflict of interest in conducting this research study.

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