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RESEARCH ARTICLE
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An On-Site Post-Event Survey of the 2022 Mw 6.1 Western Pasaman Sumatera Destructive Earthquake

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Abstract. On February 25, 2022 at 08:39:29 Local Time an unexpected earthquake with a magnitude of 6.1 Mw struck the Western part of Sumatera, onshore, and located on the blind fault. It is very likely that the earthquake was from Angkola Fault, but there is still a possibility that there are still other active faults in this area that have not been mapped yet. The areas that were affected by the earthquake are Pasaman, Western Pasaman, Limapuluh Kota, Padang Pariaman and Agam regencies. The focal mechanism from BMKG show that the dominant mechanism of this earthquake was the right lateral (dextral) strike movement. The worst devastation was in Western Pasaman and the damage from this earthquake was wide spread. An estimated 6627 houses have been destroyed and 70 mosques were damaged, 41 offices were devastated, 208 schools and educational institutions, 25 medical infrastructures, and 5 bridges were damaged. An on-site post-event survey was carried out to investigate the effects. We conduct mapping ground ruptures and cracking in an effort to find surface expression of fault rupture. Right after the main shock, a few seismometers were deployed near expected epicenter. By using macro seismic observation, micro seismic measurement, and impact documentation, we also find collateral impact that is flash flood and soil landslide which broken some access points. The destructive earthquake is a reminder expected the serious future seismic threats to comply implementation of the Building Codes.

Keywords: destructive earthquake, hydrological landslide, flash flood, building, fault.

INTRODUCTION

On February 25, 2022 at 08:39:29 Local Time an unexpected earthquake with a magnitude of 6.1 Mw struck the Western part of Sumatera, onshore, and located on the blind fault. The epicenter was located exactly at 0.15°N, and 99.98°E (Fig. 1). The epicenter of the earthquake was located 17 km. north-east of Western Pasaman and at a land depth of 10Km, with its effects felt around the region including in Singapore and Malaysia. The previous earthquake (08:35:51 Local Time) was the foreshock, the Mw 5.2 earthquake at a land depth of 10Km. The foreshock was located at 0.14°N, and 99.99°E. Due to its location it is more proper to call this earthquake the Western Pasaman 2022 earthquake. This earthquake was an active fault earthquake due to the strike slip of the Sumatran fault system. Its focal depth was 10 km according to BMKG (2022).

From 2022 February 26th to March 3rd, an on-site post-event survey team organized by the Earthquake and Tsunami Center, National Agency for Meteorology Climatology and Geophysics (BMKG) did post near-field survey investigated the effects of the Western Pasaman Earthquake in the near epicenter. The team was led by Dr. Sugeng Pribadi of Sub-Coordinator of Earthquake Operational Management BMKG, and included Admiral Musa Julius of Earthquake Mitigation Staff, Ade Andika Saputra of Earthquake Information Staff, and Dedy

Hermanto of Padang Panjang Geophysical Station Staff. Others who contributed to this paper include Rahmat Triyono, Dr. Supriyanto Rohadi, and Dr. Daryono of BMKG, and Command Center of Indonesian Disaster Management Agency.

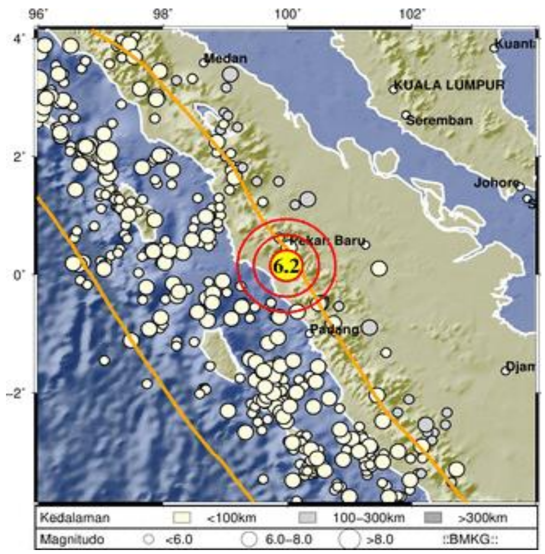
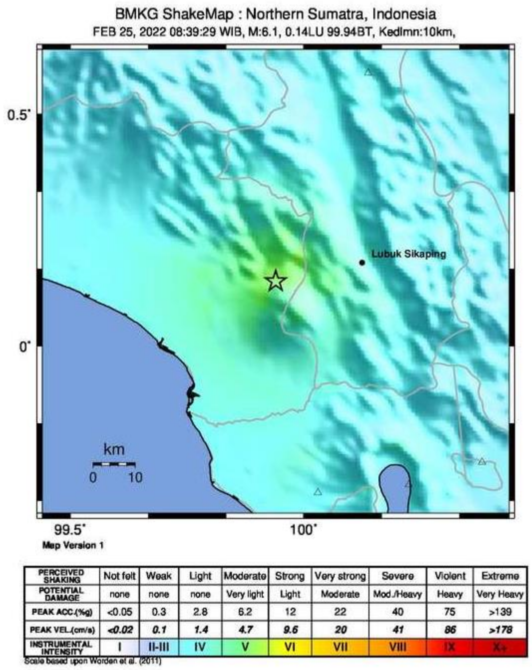


Fig.1. The 2022 Mw 6.1 Western Pasaman Earthquake Epicenter Map

Source: BMKG

The BMKG noted that about 283 aftershocks had shaken the region since Friday, 25 February 2022 with the strongest measuring magnitude 5.1. The earthquake was felt in three Provinces that is Western Sumatera, North Sumatera, and Riau. The areas that were affected by the earthquake are Pasaman, Western Pasaman, Limapuluh Kota, Padang Pariaman and Agam regencies. This paper presents the observations of four (4) members of the BMKG earthquake survey team that assessed the earthquake damage and its collateral impact. **Fig. 3** shows the seismicity of Sumatera, which relates mostly to the subduction of the Indian Ocean plate under the Eurasian plate (on which Sumatera sits). However, it is thought that the earthquake was not due to subduction, but rather to a secondary effect of subduction that compresses the Eurasian plate in a N-S direction, and puts strain on local faults, especially those trending NW-SE. The focal mechanism from BMKG shows that the dominant mechanism of this earthquake was the right lateral (dextral) strike slip. The position of the earthquake that was far from the subduction zone with a very shallow depth (only 10 km) and dominant mechanism of strike slip show that the earthquake was not from a subduction. However, the position of the earthquake was not aligned with the Sumatra Fault which has been observed, so it was estimated that the earthquake was also not from the mapped fault. The team conducted early identification of affected areas by using macro seismic observation, micro zonation measurement, and impact documentation.

It is very likely that the earthquake was from the Angkola Fault, but there is still a possibility that there are still other active faults in this area that have not been mapped yet. Some researchers call the source of this earthquake by the name of Talamau Fault. At Simpang Ampat, Kinali, Kajai, and Talu villages the intensity was recorded at VIII MMI scale, VII MMI at Lubuk Sikaping and Malampah subdistricts, VI MMI at Agam, Tanah Datar and Limapuluh Kota regencies, V MMI at Payakumbuh, Bukit Tinggi and Padang Panjang cities, IV MMI at Pariaman and Padang Pariaman regencies, III MMI at Kampar, and Rokan Hulu regencies (Riau Province). In total, the death toll continues to rise and the latest official estimate is that 27 people died, 52 people were seriously injured, 405 people were moderately injured, and up to 19221 people have been left homeless, at the mercy of torrential rain and continuing aftershocks.



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.05	0.3	2.8	6.2	12	22	40	75	>139
PEAK VEL.(cm/s)	<0.02	0.1	1.4	4.7	9.6	20	41	86	>178
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Fig.2. The 2022 Mw 6.1 Western Pasaman Earthquake Intensity Map (Shake-map)

Source: BMKG

The worst devastation was in Western Pasaman and the damage from this earthquake was widespread. An estimated 6627 houses have been destroyed and 70 mosques were damaged, 41 offices were devastated, 208 schools and educational institutions, 25 medical infrastructures, and 5 bridges were damaged. The earthquake has disproportionately affected children and the elderly, as many were not able to move quickly enough to safety. Many people from the surrounding areas are being taken to hospitals in Yarsi Simpang Ampat and Local Official Public Hospital in Pasaman Barat, which are very stretched.

DATA AND METHODS

Indonesia is uniquely located geologically as well as geophysically since it is situated at the confluence of three earth major plates: Pacific Plate, Eurasian Plate, and Indian Ocean-Australian Plate [1]. According to the Plate Tectonic Theory, tectonic activities are concentrated at plate margins [2]. And activities are highest where two or more plates collide in the so-called triple junction [3]. It is therefore no wonder that the Indonesian islands are very disaster prone [4]. At this Triple Junction three natural dynamics manifest themselves at the fullest, these are the Earth Dynamics, the Ocean Dynamics, and the Atmospheric Dynamics [5]. And it is only very recently that men have learned there is a close connection between ocean and atmospheric processes and between earth and ocean processes [6]. Earth, Ocean and Atmospheric disasters will manifest themselves at the fullest in the Indonesian islands [7].

Three tectonic units characterize the island of Sumatra. From Western to East these are: Sumatra low angle oblique subduction zone, Mentawai Thrust Fault, and Great Sumatra Fault Zone [7]. Sumatra Fault Zone is segmented into 11-12 parts [9]. At each intersection the fault system is arranged into an echelon structure [8]. More often than not the intersections are the centers of acid volcanic eruptions [10]. Large amounts of acid tuffs or pumice tuffs are accumulated at the intersections like the Toba area, the tuffs around Lake Maninjau in the Padang Highlands, the Ranau Tuffs around Lake Ranau [11].

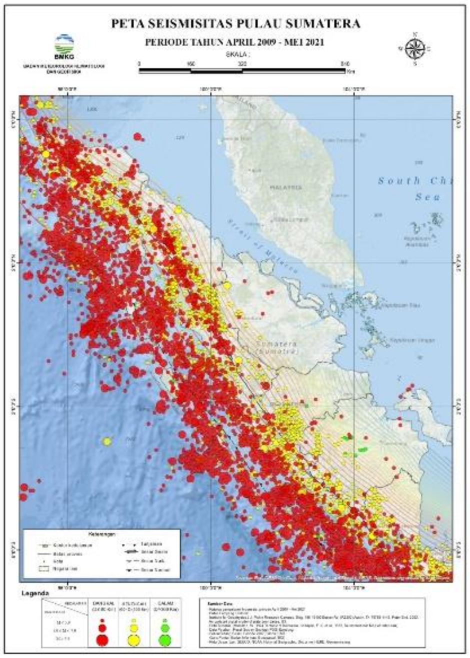


Fig.3. Seismicity map of Sumatra Island

Source: BMKG

Fig.4. Visual Observation of clock fallen at earthquake time shaking

In Sumatra Island, several updated active faults have been identified, including the Nicobar, Seulimeum-North and Aceh North Segments located on the northern part of Sumatra Island, and Mentawai fault in the western waters of Sumatera [12]. The Pidie Earthquake at the end of 2016 is important because it brought up a new fault zone, which is Pidie fault [13]. Later on, it was agreed that that earthquake zone will be included in the revised map [14].

Fig.5. Damaged House at Kajai Village

The land cover which is a productive oil palm plantation and paddy field causes the water absorbance condition to be minimum. The land condition becomes very saturated due to the rain occurring a week before. It is necessary to know that the following hydrological landslide 3 days after the main earthquake event occurred on 25 and 28 February 2022. However, based on the on-site survey and field analysis results, it was found that the two soil landslides have different systems. The first landslide was caused by the debris materials deposited after the earthquake of the mountainside and triggered by the rain while the second landslide was caused by the ground instability created by the main earthquake and induced by the rain. We choose Western Pasaman regency due to equal distribution of missions with the other teams that also did similar surveys in the other impact regencies.

Fig.6. Ground failure at the hills of Mt.Talamau (Kajai Village)

Besides that, the survey was conducted based on National Disaster Management Office information in terms of loss and damage on those regencies. On February 26 - March 3, 2022, we did a focus field survey in the Western Pasaman regency. It is located in the western part of Mt.Talamau. Furthermore, we did a field survey of aftershocks and micro-seismic in 5 sites in the Western Pasaman regency. For data acquisition and analysis equipments, we used to 2 Seismometers Short Period Lennartz LE-3D Lite, 2 Data Logger Taurus Nanometrics, Distance Laser Fluke 424D, Distance Laser Leica Disto A6, Compass Brunton, and for data interpretation, we used Notebook.

An earthquake with an epicenter on land can still cause a tsunami [15]. This can be easily explained. One thing to understand is that the source of an earthquake is not in the form of a point, but a fracture in the form of a rupture [16]. Therefore, although the epicenter is located on land, the formed fracture could extend to the sea, making it possible for the earthquake to trigger a tsunami [17]. An epicenter located on a coastal land can also cause a tsunami if the produced earthquake triggers a seabed landslide [18].

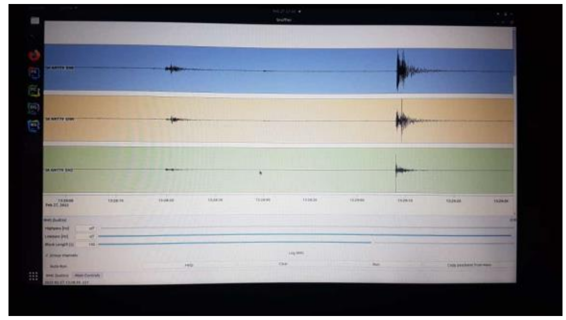


Fig.7. Aftershock recorded on the on-site detection using Seismograph at Kajai Village

Source: BMKG

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RESULT AND DISCUSSION

We collect ground ruptures and cracking in an effort to find surface expression of fault rupture. Right after the main shock, a few seismometers were deployed near the epicenter to monitor the aftershocks. The aftershock records have been made available to the public. Several people interviewed in the heavily affected areas (Kajai, Western Pasaman) reported a distinct vertical motion followed by strong horizontal shaking. Preliminary discussions with local volunteers also substantiated the high vertical component of the ground shaking.

Fig.8. Soil Landslides at Talu Village

[0.2456 N;99.9567 E]

Building Damages

The Western Pasaman earthquake caused damages to almost 6.000 residential buildings, of which 90% of the damaged buildings were located in Western Pasaman and Pasaman regency. Sinuruik, Talu, and Kajai village in Talamau sub-district, Aua Kuniang village in Pasaman sub-district, Koto Baru village in Luhak Nan Duo sub-district, and Kinali village in Kinali sub-district were some of the worst affected area in Western Pasaman regency. Furthermore, Malampah, Ladang Panjang, Binjai village in Tigo nigari sub-district were some of the worst affected areas in Pasaman regency. While in the Agam, Kota Pariaman, Padang Pariaman, and Limapuluh Kota regency, the earthquake caused minor damages.

There are two types of residential buildings which are commonly used by local people. Rumah Gadang (wooden-elevated house) which is usually used by the original people of Minang and rumah biasa/nonpanggung (landed house) which is usually used by transmigrants who mostly come from North Sumatra and Riau. Landed house suffered most damage due to the Pasaman earthquake.

Geotechnical Conditions and Ground Deformation

From a geotechnical perspective, the most pronounced effects of the earthquake are associated with directivity and soil amplification [19]. Early observation shows the heavily damaged zones concentrated in two distinct areas: one near the epicenter (Kajai, Talu, Kinali), and other further east (Malampah). It appears that directivity (and proximity to the fault rupture zone), topography, local site conditions, and the vulnerability of older unreinforced masonry homes affected the severity of the damage. These effects need to be confirmed until the detailed study on geology and seismology is completed and the fault rupture location and orientation are confirmed [20].

Fig.9. Ground Cracking at Talu Village

[0.2154 N;99.9784 E]

According to the geologic maps of the Geological Survey of Indonesia, the coastal plains of Pasaman and Western Pasaman are underlain by quaternary alluvium deposits, consisting of silt, sand, gravel and remnants of pumice tuff [21]. The Limpato roadline (**Fig. 11**) is one of the strategic road outside of the mountain areas that suffered earthquake damage [22]. It is an important link between the low-lying old town of Lubuk Sikaping and high ground located to the west, and several road points had ground cracking or soil landslides [23].

The other distinct geotechnical phenomenon was ground cracking associated with lateral spreading, settlement, permanent deformations, dynamic densification, or a combination. Lateral spreading of embankment fill soil led to the failure of a section of stone masonry retaining wall around a slope at Mt.Talamau. No evidence of sand boils or liquefaction was found in the site vicinity.

Fig. 9 shows ground cracking and settlement due to permanent deformation along a road shoulder. This road runs parallel to a stream at several locations along its length, in some places settling as much as 20 cm. The same phenomenon was observed along several bridge approaches with poorly compacted fills and river embankments through the region. There were reports of strong smells and water boils in Ganggo Hilia village. Muddy fine sand was observed that caused minor damage confirming that sand boils and small liquefaction did occur.

Many rock falls occurred in the hills near Kajai, west of Mt.Talamau and probably very close to the fault rupture area (**Fig. 6**). Some natural slopes along provincial roads near the Kajai-Talu Bridge also failed during the shaking. There were other reports of soil landslides in a few areas, followed by reported road structures, or electricity facilities on the ground affected by the earthquake.

Fig.10. Broken Road at Talu Village

[0.2127 N; 99.980 E]

Soil Landslides

Landslides in the outlying rural mountain areas induce the flash flood, trigger collateral impact, buried several villages, damaged roads, and caused unidentified victims. Few villages in Mt.Talamau valley, people and houses perished and buried under landslides. The affected area is a densely populated mix of urban and rural communities on the western slope of Mt.Talamau, an active volcano. Many houses and buildings collapsed and the tremors were felt on the valley of the Mt.Talamau as well on the nearby cities. Not only did we feel the earthquake, but we also heard the earthquake sound in Kajai village, in Mt.Talamau valley, similar to a far field boom explosion. It was started the loud boom alike falling stone and continues to 3-5 seconds voicing vibration. Its natural phenomena proved the on-site post-event survey located in the very near epicenter.

The hydrological landslide occurred at Malampah, Talu, and Kajai. Two (2) soil landslides occurred due to hydrometeorology factor and slope of hills induce the collateral impact that took place in the morning of 25 February 2022 just after the earthquake; a huge landslide took place in Talu and Kajai villages, Talamau Subdistrict. Three (3) days after the earthquake, a devastating landslide hit the provincial road in a few points in Talamau sub-district. Several traffics were stuck as some cracks and landslide materials were noticed on the provincial road connecting Pasaman and Western Pasaman, meanwhile roads are still accessible to Pasaman through Agam (**Fig. 11**). Based on the report from the Command Center of National Disaster Management Agency and the Local Disaster Management Agency, the soil landslide disaster caused damage to riverside residential units, evacuated hundreds people, and up until this article is written, there have been 2 casualties found and 3 others still not located. Information obtained from an on-site post-event survey done on 26 February – 3 March 2022 shows that there were several ground cracks with ±30 cm length in the strategic area of the landslide after the earthquake event. Heavy rain occurring until Thursday, 3 March 2022 caused the landslide on 25 February 2022, on 08.40 AM and 1 March 2022, on 08.22 PM Local Time.

Fig.11. Totally Broken Road at Limpato Sub-Village [0.1749 N; 99.962 E]

Fig.12. Ground failure at residential area Kajai Village

The soil landslide affected area is located in Talamau Mountainside area with a high dip level which made it a location with high potential of soil landslide disaster. It was not easy to access the affected area, and it took around an hour driving from the regency center to get there. The roads are narrow, but accessible by vehicles. As in most areas in Indonesia, land diversion is common to be found, and we can find two in Talu and Kajai Village. The hill that became the crown spot of the landslide is a palm oil and rubber plantation which had become illegal logging. The plantation was previously a green forest.

The soil landslide affected area in Kajai and Talu underwent addition of ground mass to be too saturated due to the earthquake process from a 3 days before landslide (25 February) by being rained heavily for two consecutive days. The soil landslide is expected to occur because of the rapid increase of ground mass increase one day before the landslide due to the reoccurring heavy rain. The landslide event in Kajai and Talu Village is a highly destructive hydrological landslide with a thickness reaching 20 meters. It led to the severe damage of 40 residences, heavy damage to 8 residences, and average damage to 10 residences. Electricity and telecommunication have been cut off in several areas.

CONCLUSION

In Mw 6.1 Western Pasaman Earthquake of February 25, 2022 was strongly damaging and generated losses on a few sites surveyed in Western Pasaman. According to the earthquake source, this event was associated with the Talamau active fault, which the seismicity first mapped since February 25, 2022. The mapped active faults before only mention Angkola and Sianok faults. This event struck houses, public facilities, and human injuries. Beside the seismic survey, we also did socialize updated earthquake information in terms of let local people know the current status of local seismicity. Observations on structural buildings which damage show that few have collapsed due to material failure and inappropriate design.

The earthquake is a reminder of expected serious future seismic threats faced by Pasaman and Western Pasaman. Most of the damaged buildings and dwelling houses were due to unsuited engineering, poor masonry, and the use of poor quality of building materials. In many cases, there was a tendency to build houses with too heavy roofings. In most cases, heavy cracks occurred at the joints (poor engineering/architecture and poor masonry). Awareness of the threat of earthquakes has to be intensified. This is for the sake of the society itself.

SUGGESTION

In fact, mitigation of natural disasters consists of all the planned and directed efforts to reduce the impact of all natural disasters [24]. It comprises the preparedness phase: making the public aware of the impending danger and guiding the public through training, routine drill and socialization on how to save oneself in a coordinated and a well planned manner [25].

The most important aspect of the preparedness phase is avoiding panic. People should know what to do and where to go [26]. Regular training and drills in a well planned way will avoid panic during the real event. Land use planning based on geophysical information i.e. seismic zoning and micro zonation is one of the most useful measures in the mitigation phase followed by the implementation of the Building Codes, particularly with high rise buildings in cities [27]. In the rural areas it is of high importance to teach the people how to apply earthquake resistant designs to simple dwelling houses [28]. The most important thing is that policies are implemented.

That means there should be inspections to see to it that the Building Codes are implemented. Without this the Building Code is useless. Indonesia has a Building Code formulated in the early 70th. It has been reviewed regularly and updated with new information with the development of new technologies. Building Codes also apply to government buildings and other units of the infrastructures such as roads, toll roads, bridges, dams, and stadiums etc.

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REFERENCES

[1] Agus, R.N., Suardi, I., Sipayung, R. and Sianipar, D. (2018). *Local seismicity pattern around Mt. Pandan, East Java according to February 2016 earthquake swarm activity*. AIP Conference Proceedings 1987, 020034.

[2] Banyunegoro, V.H., Alatas, Z.A., Jihad, A., Eridawati, and Umar, M. (2019). *Probabilistic Seismic Hazard Analysis for Aceh Region.* IOP Conference Series: Earth and Environmental Science, Volume 273. 012015.

[3] Banyunegoro, V.H., Umar, M., and Idris. Y. (2020) *Seismic microtremor experiment to determine seismic vulnerability of North Aceh*. IOP Conference Series: Materials Science and Engineering, Volume 846, 012053.

[4] Banyunegoro, V.H., Firdausi, R., Umar, M., and Idris, Y. (2021). *Shallow One-Dimensional Shear Wave Velocity Structure in Lhokseumawe, Aceh-Indonesia.* J. Phys.: Conf. Ser. 1811 012078

[5] Cahyaningrum, A.P., Nugraha, A.D., and Puspito, N.T. (2015). *Earthquake hypocenter relocation using double difference method in East Java and surrounding areas.* AIP Conference Proceedings 1658, 030021.

[6] Daniarsyad, G., and Suardi, I. (2017). *Stress triggering among MW≥6.0 significant earthquakes in Manokwari Trough.* AIP Conference Proceedings 1857, 020014.

[7] Hududillah, T.H., Simanjuntak, A.V.H., and Husni, M. (2017). *Identification of active fault using analysis of derivatives with vertical second based on gravity anomaly data (Case study: Seulimeum fault in Sumatera fault system).* AIP Conference Proceedings 1857, 030004.

[8] Kesumastuti, L., Marsono, A., Yatimantoro, T., and Pribadi, S. (2017). *Determination of the earthquake source parameters using W-Phase inversion method and its uses for tsunami modelling.* AIP Conference Proceedings 1857, 090006.

[9] National Center for Earthquake Study. (2017). *Indonesia Map for Earthquake Source and Hazard.* Jakarta: Ministry of Public Works and Resident. ISBN 978-602-5489-01-3. In Bahasa Language.

[10] Octhav, A., Julius, A.M., Muzli, and Rudyanto, A. (2017). *Modified of Ground Motion Prediction Equation in Indonesia, case study: South and South-East of Sulawesi* at 2011-2015. AIP Conf. Proc. 1857, 020003.

[11] Pandadaran, S. H., Julius, A.M., Widiarso, A., and Kurniawan, S.E. (2019). *Comparison of Ground Motion Atenuation Models for West Sumatra and Bengkulu regions based on distant Subduction Interface and Intralab Earthquake*. Proceedings Joint Convention Yogyakarta 2019, HAGI-IAGI-IAFMI-IATMI (JCY 2019). ISBN 978-979-8126-37-6.

[12] Puteri, D.M., Affandi, A.K., Sailah, S. Hudayat, N., and Zawawi, M.K. (2019). *Analysis of peak ground acceleration (PGA) using the probabilistic seismic hazard analysis (PSHA) method for Bengkulu earthquake of 1900 – 2017 period.* Journal of Physics: Conference Series, Volume 1282, 012054.

[13] Rahman, A., Marsono. A., & Rudyanto, A. (2017). *Rapid magnitude estimation using τC method for earthquake early warning system (Case study in Sumatra).* AIP Conference Proceedings 1857, 020017.

[14] Rahman, A., Vita, A.N., and Rohadi, S. (2021). *Seismic gap identification along Sunda trench using mapping analysis of energy accumulation zone.* AIP Conference Proceedings 2320, 040015.

[15] Sagala, R.A., Harjadi, P.P.J., Heryandoko, N., & Sianipar, D. (2017). *Detailed seismotectonic analysis of Sumatra subduction zone revealed by high precision earthquake location.* AIP Conference Proceedings 1857 (1), 020015.

[16] Serhalawan, Y.R., Sianipar, D., & Suardi, I. (2017). *The January 25th, 2014 Kebumen*

earthquake: A normal faulting in subduction zone of Southern Java. AIP Conference Proceedings 1857 (1), 030002.

[17] Setiadi, T. A. P., Rohadi, S., & Heryandoko, N. (2017). *Earthquake relocation in Mollucas Sea using teleseismic double difference method for tectonic setting analysis.* AIP Conference Proceedings 1857, 020007.

[18] Sipayung, R., Alhafiz, M.R., Agus, R.N., & Sianipar, D. (2018). *Relocation of the February 2016 Mt. Pandan earthquake sequence using double difference with waveform cross correlation.* AIP Conference Proceedings 1987 (1), 020036.

[19] Sipayung, R., Sianipar, D., Prayoedhi, S., Daryono, Arifin, J., Simanjuntak, A.V.H., Umar, M., Prabu, S., Daniarsyad, G., Haryanta, Putranto, N., dan Azimi, A. (2019). *Revisiting The 2018 Kalibening Earthquake Sequence in Central Java: Call for the Revision of Earthquake Hazard.* IOP Conference Series: Earth and Environmental Science, Volume 273, 012018.

[20] Simanjuntak, A.V.H., Umar, M., Qadariyah, Setiawan, Y., and Irwandi. (2019). *Source Mechanism Analysis by Using Tensor Moment Inversion (Study Case: Pidie Jaya Earthquake in 2016 December 7th).* IOP Conference Series: Earth and Environmental Science, Volume 273, 012021.

[21] Simanjuntak, A.V.H., Husni, M. and Syirojudin, M. (2017). *Subsurface structure identification of active fault based on magnetic anomaly data (Case study: Toru fault in Sumatera fault system).* AIP Conference Proceedings 1857, 030003.

[22] Simanjuntak, A.V.H., Umar, M., and Rahmayani, F. (2018). *Microtremor survey to investigate seismic vulnerability around the Seulimum Fault, Aceh Besar-Indonesia.* IOP Conf. Series: Materials Science and Engineering 352, 012046.

[23] Simanjuntak, A.V.H., Umar, M., and Sipayung, R. (2018). *Earthquake relocation using HypoDDMethod to investigate active fault system in Southeast Aceh.* IOP Conf. Series: Journal of Physics: Conf. Series 1116, 032033.

[24] Taruna, R. M., Banyunegoro, V. H. (2018). *Earthquake Relocation Using Double Difference Method for 2D Modelling of Subducting Slab and Back Arc Thrust in West Nusa Tenggara.* Jurnal Penelitian Fisika dan Aplikasinya (JPFA), v. 8, n. 2, p. 132-143. ISSN 2477-1775.

[25] Taruna, R.M., Banyunegoro, V.H., and Daniarsyad, G. (2018). *Peak ground acceleration at surface for Mataram city with a return period of 2500 years using probabilistic method*. MATEC Web Conf. Volume 195, 2018 :03019.

[26] Taruna, R.M., Irianti, D.I., Septiadhi, A., and Pratiwi, A. (2021). *Identification of 13th July 2019 Sumbawa earthquake source using double difference method.* Proceeding Proceeding International Conference on Science (ICST).

[27] Vita, A.N., Putra, S.Y.S., Subakti, H., and Muslim, B. (2017). *Identification of ionospheric GPS TEC anomalies prior to earthquake in Sumatra between 2007-2012 using correlation technique.* AIP Conference Proceedings 1857, 040007.

[28] Vita, A.N, Perdana, Y.H., Ngadmanto, D., and Rohadi, S. (2021). Site *effect study of Garut regency using microtremor measurement.* AIP Conference Proceedings 2320, 040016