THE VELOCITY MODEL IDENTIFICATION IN EARTHQUAKES PARAMETERS DETERMINATION IN THE NEAR REGIONAL OF THE BANGKA NPP CANDIDATE SITE

Yuni Indrawati[1,2] and Wiwit Suryanto[1]*
[1]Department of Physics, University of Gadjah Mada, Sekip Utara Bulaksumur, Yogyakarta 55281, Indonesia
[2]Research Center for Nuclear Reactor Technology, National Research and Innovation Agency, KST BJ Habibie, Tangerang Selatan, Banten 15310, Indonesia

*** Corresponding author:**

e-mail: ws@ugm.ac.id
phone/WA: +62815-78600075

Received: 02-01-2023
Revision Received: 10-02-2023
Accepted: 16-06-2023

DOI :
10.17146/jstni.2023.24.1.6774

Keywords: Seismic aspect, Velocity model, Earthquake parameter, NPP site

Abstract Collecting information and earthquake investigation must be carried out to ensure the safety of the nuclear installation candidate site from seismic aspects. Accurate earthquake location data is essential for seismological studies. The accuracy must be improved from the velocity model factor in determining earthquake parameters in a limited number of stations and less azimuth coverage. The study aims to get the most appropriate velocity model for determining earthquake parameters in the near regional of the Bangka NPP candidate site. The study uses earthquake seismic data in Bangka seismic network with variations of the H-S, Crust 2.0, and TPI velocity models to determine earthquake parameters. The most appropriate velocity model is determined based on the comparison with BMKG results and the smallest errors in identifying earthquake parameters. The results show almost the same epicenter and origin time but different earthquake depths. The TPI velocity model best represents the velocity model in the near regional of the Bangka NPP candidate site. TPI falls into the criteria of tectonic earthquake type and most errors (latitude, longitude, and depth) in earthquake parameters determination are the smallest among other velocity models.

INTRODUCTION

Based on the Nuclear Energy Regulatory Agency (BAPETEN) Head Regulation No. 8 of 2013 concerning evaluating nuclear installation sites for seismic aspects, the Site Evaluation Applicant must collect information and investigate the seismicity of seismological conditions (1). This must be done to ensure the nuclear installation candidate site is safe from seismic aspects. Seismic data collection or monitoring is carried out by installing earthquake instruments and earthquake measuring instruments are installed at specific intervals to allow seismotectonic interpretation. Recorded data from earthquake instruments were analyzed to obtain earthquake parameters such as epicenter, origin time, depth, magnitude, and source mechanism. Information about accurate earthquake locations is crucial for seismological studies (2,3). Determining the bias-free earthquake locations is still the most important and challenging task (4). The accuracy of earthquake location is affected by several things, such as uncertainties of the picked arrival times, azimuthal gap, number of stations, and the velocity model.

Earthquake parameters identified using the pick-based method make the resulting catalog's quality depend on the pick's precision (5). Although manual picking is time-consuming and many automatic picking methods were proposed, manual picking is considered the most accurate way to access the arrival time (6). It is challenging to associate phase picks with seismic events (7,8). Missed detection can happen in multiple events with short interevent times or overlapping events due to difficulty assigning picks to phases and events (7). Another consideration is the azimuthal gap which is the maximum angle between two adjacent seismic stations (9). The smaller the azimuthal gap, the smaller the location uncertainty (10). The location accuracy will decrease if the azimuthal gap is more than 180° (9). If proper azimuthal coverage is achieved and a realistic velocity model is used, the earthquake's location can be better determined (11). To obtain uniform azimuthal coverage, a minimum number of stations is required. The network must be sufficiently dense to meet the azimuth coverage criteria (better than 180°) (9).

An essential source of error in influencing the accuracy of determining the location of an earthquake is the velocity model (12,13). The ray paths between hypocenters and receivers are determined by the velocity structure (14). In general, determining earthquake parameters using the 1D velocity model does not consider lateral variations. Using the simplified 1D velocity model, significant errors in earthquake locations can occur in areas with strong lateral variations and irregular topographic surface (15). Many studies have found that velocity model errors lead to inaccuracies in determining earthquake parameters, especially the location of the earthquake, such as (14), (16), and (17). The better the velocity model is defined, the more accurate the earthquake location will be. Therefore, It is crucial to determine the appropriate velocity model to get precise earthquake parameters, especially around the candidate of the nuclear installation site.

One of Indonesia's Nuclear Power Plant (NPP) candidate sites is the Bangka NPP candidate site. Based on the feasibility study, there are two preferred sites, Muntok, West Bangka and Sebagin, South Bangka (18). Several earthquake instruments have been installed around the Bangka NPP candidate sites to obtain seismic information. With a limited number of stations and less azimuth coverage, the accuracy of determining earthquake parameters must be improved from the velocity model factor. Due to limited earthquake data, conventional method like the VELEST program cannot be used. Therefore, in this study, the appropriate velocity model for the near regional of the Bangka NPP candidate site was sought by using several velocity models to determine earthquake parameters, the results of which were controlled using the Meteorological, Climatological, and Geophysical Agency (BMKG) results (19) and errors processing. With insufficient data, namely only five earthquakes identified within a 100 km radius of the Bangka NPP candidate site, the most appropriate velocity model is hoped to be obtained.

REGIONAL GEOLOGY

The geology of Bangka Island (Figure 1) consists of the Karbon-Permian Pemali complex, which is the oldest Formation on Bangka Island, then covered by the late Permian to early Trias Permian Tanjunggenting Formation with the breakthrough of the late Triassic to early Jurassic Klabat Granite which the late Miocene to early Pleistocene Ranggam Formation then deposited (20). The Pemali complex consists of phyllite and schist with intercalation quartzite and limestone lenses. The Tanjunggenting Formation consists of alternations of meta-sandstones, sandstones, clayey sandstones, and claystone with limestone lenses and iron oxide (20,21). The Klabat granite consists of granite, granodiorite, adamalite, diorite, and quartz diorite (20,21). The Ranggam Formation consists of alternating sandstones, claystones, and tuffaceous claystones with the intercalation of thin layers of siltstone and organic matter (20).

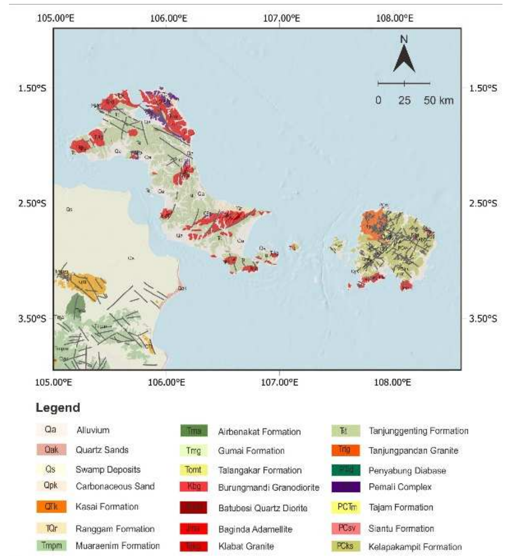

Figure 1. Geological Map of The Bangka Island and Its Surroundings (20–24).

The geological structure on Bangka Island consists of joints, folds, lineaments, and faults (25). The fault structures are reverse, strike-slip, and normal faults and folds trending northwest-southeast and northeast-southwest to north-south (20,21). Meanwhile, the lineament rose diagram based on the SRTM imagery is relatively dominant in the northwest-southeast direction, while the folds covering the Tanjunggenting Formation and the Ranggam Formation trend northeast-southwest (25).

Based on Baharudin and Sidharto (1995), the geology of Belitung Island (Figure 1) consists of Permo-Carboniferous Kelapakampit Formation, Tajam Formation that probably interfingers with the Permo-Carboinferous Kelapakampit, Siantu Formation interfingering with the Kelapakampit Formation, 208 to 245 m.y. Tanjungpandan Granite, 160-208 m.y. Adamellite Baginda, 115-160 m.y. Batubesi Quartz Diorite, and 115-160 m.y. Burungmandi Granodiorite (24). Kelapakampit Formation is a flysch type sediments that consist of metasandstones alternating with slate, mudstone, shale, tuffaceous siltstone, and chert. Tajam Formation consists of quartz sandstone intercalated by siltstone. Siantu Formation consists of lava basalt and volcanic breccia. Tanjungpandan Granite is the largest pluton on Belitung island and has been mineralized and located in the northwest.

METHODOLOGY

This research uses near regional earthquake seismic data located in Bangka and Sumatra within a 100 km radius of the Bangka NPP candidate site. The data used is National Nuclear Energy Agency (BATAN), now National Research and Innovation Agency (BRIN) seismic data recorded on the Bangka seismic network. The selected earthquake data is the 2017-2019 earthquakes data identified in the BMKG earthquake catalog (19). Five earthquakes were within the radius area in the catalog (Table 1).

Earthquake data processing uses a linearized inversion method in Seisan software (26). Seisan uses a modified hypocenter program from HYPOCENTER, a combination of the HYPO71 and HYPOINVERSE algorithms (27). The main input files are station locations and velocity model. The stations used are JBS, SLT, TBA, TPG, MTK, and SBG stations spread throughout Bangka Island. Station seismic data that is processed depends on the data availability on the earthquake at that time. The velocity model used varies from regional to local, including the H-S (28), Crust 2.0 (29), and TPI velocity model (30) (Figure 2).

The detailed processing flow is shown in Figure 3. The seismic data is picked manually by the P wave in the vertical component and/or the S wave in one of the horizontal components. A band pass filter is applied when the waveform phase is difficult to identify. The trial and error filtering from 1-8 Hz are made until the phase can be identified clearly. The same treatment was carried out for different velocity models. The study only focuses on variations in the velocity model while picking and other parameters are fixed. The limitation of this study is the appropriate velocity model determination is only based on the geological condition and the analysis of the results. Even though the earthquake data is limited, earthquake parameter results will be validated with the results of the BMKG catalog (19) and the quality of the results is controlled using latitude error, longitude error, depth error, and RMS.

Table 1. Identification of Earthquakes Within a 100 km Radius of The Bangka NPP Candidate Site by BMKG (19)

Date	Origin time	Latitude (°)	Longitude (°)	Depth (km)	Magnitude
27/01/2017	00:08:54.558	-1.46	105.63	10	4.3
30/01/2018	12:16:50.031	-1.53	105.55	10	3.6
09/02/2018	19:37:50.305	-2.63	105.01	10	3
08/06/2018	18:50:25.783	-1.73	105.35	10	3.4
16/11/2019	03:05:22.33	-3.48	105.87	10	3.5

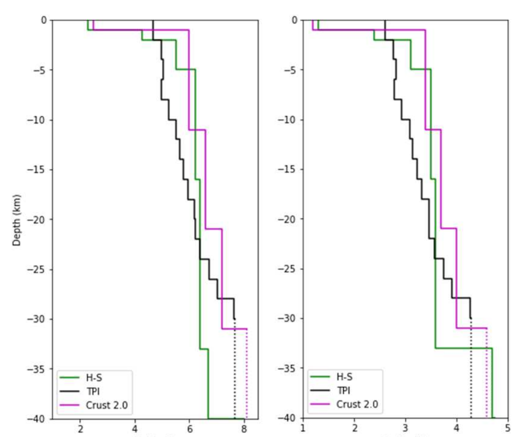

Figure 2. The Velocity Models Used in Earthquake Parameters Determination in The Bangka Region (Dotted Line is Considered as Half-Space).

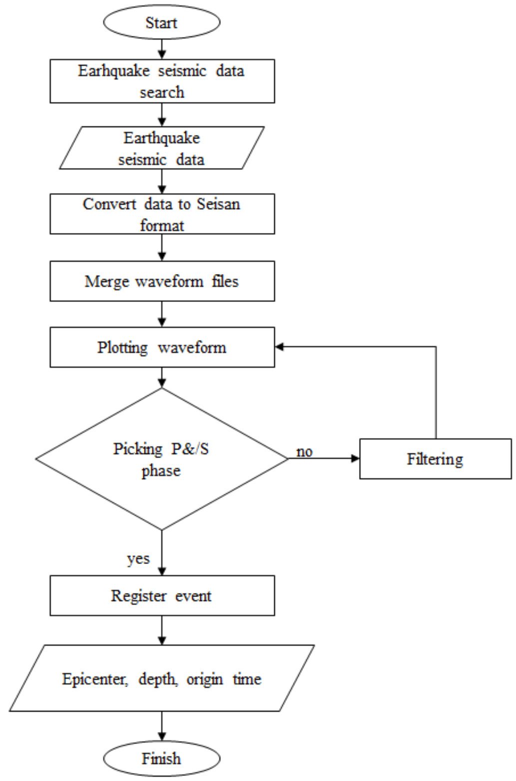

Figure 3. Flow Chart of Earthquake Parameter Determination Using Seisan Software.

Table 2. The Parameter Differences between Each Velocity Model

Parameters	Velocity Model		
	H-S	**Crust 2.0**	**TPI**
Type	regional	regional	local
Coverage	Sumatra	2° from the center of the circle	TPI, Tanjung Pandan, Belitung
Max. velocity model depth used	40 km	31 km	30 km
Number of layers	7	5	16
Epicenter position with BMKG	close	close	close
Depth (Tectonic earthquake type)	unreasonable	unreasonable	reasonable

RESULTS AND DISCUSSION

Regional to local velocity model variation was carried out to determine which velocity model represents the near regional area of the Bangka NPP candidate site. The differences in the velocity models used in terms of the velocity model type and the results are shown in Table 2. The H-S and Crust 2.0 velocity models are regional velocity models that cover the geology of the study area, while the TPI velocity model is a local velocity model resulting from the receiver function at TPI, Tanjung Pandan, Belitung which represents the geology of the area. All the velocity models used are up to a depth of 30-40 km, with the last layer considered half-space. Each velocity model has a different number of layers and more detail in the TPI local velocity model.

The results of identifying earthquake parameters using the Bangka seismic network with several velocity models are shown in Table 3 and Figure 4. Based on latitude, longitude, and depth errors, the 16 November 2019 earthquake for all velocity models may have a significant error caused by too large azimuth gap. Therefore, the earthquake is not used for further interpretation. In contrast, the other earthquakes have errors and RMS which are still acceptable for the Bangka station network distribution. The epicenter and origin time of four earthquakes using three velocity models are close to the BMKG results. Although the parameters used in earthquake identification are different such as the sensor, the velocity model used, the distribution of stations, the processing tool, and the subjectivity of picking by BMKG, the difference in epicenter and origin time is close enough to be acceptable. However, BMKG only provides earthquake catalogs and no more detailed information regarding these parameters, so further comparisons cannot be made.

Nevertheless, several earthquakes in each velocity model produce different depths, proving that the velocity model affects the determination of the earthquake's depth. Most earthquakes with the Crust 2.0 and H-S velocity models have an unreasonable depth for the tectonic earthquake type. Determining the earthquake's depth on 30 January 2018 using the Crust 2.0 velocity model resulted in an unreasonable depth of 0.1 km. In comparison, the depth for the TPI velocity model can still be considered reasonable.

Table 3. The Results of Earthquake Parameters Determination from Several Velocity Models.

Velocity model	Origin time	Lat (°)	Long (°)	Depth (km)	Errors (km)			RMS	Comment
					Lat	Long	Depth		
H-S	27/01/2017, 00:08:53.5	-1.567	105.474	0.8	8.5	2.3	3.7	0.3	Acc
	30/01/2018, 12:16:49.3	-1.607	105.473	1	3.7	3.4	2.9	0.4	Acc
	09/02/2018, 19:37:47.2	-2.544	104.961	1	13.5	18.4	8.3	0.5	Acc
	08/06/2018, 18:50:25.8	-1.544	105.509	2.5	8.2	6.6	15.9	0.4	Acc
	16/11/2019, 03:05:22.0	-3.43	105.821	1	62.6	26.9	0	0	Unacc
Crust 2.0	27/01/2017, 00:08:53.6	-1.596	105.472	1	11.9	3.1	5.8	0.3	Acc
	30/01/2018, 12:16:49.4	-1.596	105.472	0.1	4.7	3.4	3.4	0.4	Acc
	09/02/2018, 19:37:47.6	-2.555	104.953	1	16.2	26.2	11.6	0.6	Acc
	08/06/2018, 18:50:25.9	-1.530	105.492	6.1	4	4.5	3.5	0.1	Acc
	16/11/2019, 03:05:25.3	-3.244	105.925	0	174.6	115	999.9	0.3	Unacc
TPI	27/01/2017, 00:08:52.9	-1.592	105.481	8.2	5.7	3.3	4.2	0.4	Acc
	30/01/2018, 12:16:48.6	-1.648	105.479	3.6	3.7	2.5	9.1	0.3	Acc
	09/02/2018, 19:37:47.3	-2.511	105.017	8.3	5.9	9.2	10.3	0.8	Acc
	08/06/2018, 18:50:25.7	-1.600	105.484	9.9	3.9	3.3	2.2	0.1	Acc
	16/11/2019, 03:05:22.5	-3.335	105.921	1	66.5	11.9	0	0.1	Unacc

Note: Lat = Latitude, Long = Longitude, RMS = Root Mean Square, Acc = Acceptable, Unacc = Unacceptable

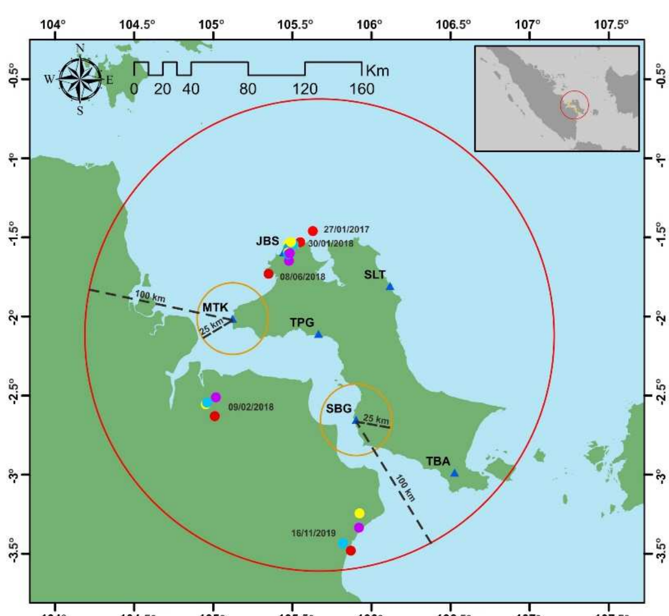

Figure 4. Distribution of Earthquake Epicenters from TPI (Purple), H-S (Blue), Crust 2.0 (Yellow), and BMKG (Red) Velocity Models in The Near Regional of The Bangka NPP Candidate Site.

The velocity model is quite sensitive to depth. Most of the depths generated by the Crust 2.0 and H-S velocity models have very shallow depths. For example, the 30 January 2018 earthquake on the Crust 2.0 velocity model produces a depth of 0,1 km which is unreasonable for a tectonic earthquake type. Faults occur when two planes slip each other which is impossible on the surface. Most of the depths obtained from the TPI velocity model fall into the criteria for tectonic earthquake depth. It is supported by (31), that classifies shallow earthquakes based on the faulting style which the depth distribution of the normal, reverse, and strike-slip fault earthquakes do not exist at 0-5 km depth. This is also supported by almost the same geological conditions between the Bangka and Tanjung Pandan, Belitung areas. Furthermore, almost all Seisan earthquake processing using the TPI velocity model has the smallest latitude, longitude, and depth error compared to the H-S and Crust 2.0 velocity models. Therefore, based on the analysis of the results, the TPI velocity model is more representative in the Bangka region.

This study has several limitations, such as the number of stations, picking quality, and lithological variations in determining earthquake parameters. Only about 4 or 5 stations can be processed for each earthquake. Nevertheless, the results must be considered because the stations are locally in the Bangka region, which is expected to represent the Bangka area. The picking quality in this study was overcome by only identifying clear phases and controlled by errors (latitude, longitude, depth) and the RMS. Another limitation is the variation of lithology which significantly affects earthquake parameter determination. The selected velocity models are considered to be able to cover the geological conditions of the Bangka area and its surroundings. For the TPI velocity model, even though it represents the TPI, Tanjung Pandan, Belitung area, the geological conditions are almost identical to the Bangka area.

With the existing limitations, an appropriate velocity model for the near regional Bangka NPP candidate site is still needed and the results are acceptable. The velocity model greatly influences the results of the earthquake parameters and earthquake parameter information is essential data in seismic hazard analysis. Using an inaccurate velocity model will result in less precise earthquake parameters which can endanger the safety and security of the NPP candidate site from a seismic aspect.

CONCLUSION

Determination of earthquake parameters in the near regional of the Bangka NPP candidate site using the H-S, Crust 2.0, and TPI velocity models results in almost the exact epicenter and origin time but different earthquake depths. Most earthquakes with the Crust 2.0 and H-S velocity models have an unreasonable depth for the tectonic earthquake type. In contrast, the TPI velocity model falls into the criteria. Otherwise, most errors (latitude, longitude, and depth) in earthquake parameters determination use the TPI velocity model, which is the smallest among other velocity models. Therefore, of the three velocity models, the TPI velocity model is most appropriate to represent the Bangka velocity model in the near regional of the Bangka NPP candidate site. Suitable local velocity models can improve the accuracy of determining earthquake parameters which are essential data in seismic hazard analysis to ensure the safety and security of NPP candidate sites. However, some limitations, such as data and station limitations, picking quality, and lithological variations may affect the reliability of the results. Further research can be carried out by minimizing the effect of the limitations, one of which is increasing the number of stations so that the azimuth gap is small.

ACKNOWLEDGEMENTS

This study was financially supported by the 2020-2021 Center for Education and Training Ministry of Research and Technology/BRIN Saintek Scholarship and the 2022 BRIN Advanced Scholarship.

REFERENCES

1. BAPETEN. Peraturan Kepala Badan Pengawas Tenaga Nuklir Nomor 8 Tahun 2013 tentang Evaluasi Tapak Instalasi Nuklir untuk Aspek Kegempaan. 2013.
2. Wagner M, Husen S, Lomax A, Kissling E, Giardini D. High-precision earthquake locations in Switzerland using regional secondary arrivals in a 3-D velocity model. Geophys J Int [Internet]. 2013 Jun 1;193(3):1589–607. Available from: https://doi.org/10.1093/gji/ggt052
3. Gesret A, Desassis N, Noble M, Romary T, Maisons C. Propagation of the velocity model uncertainties to the seismic event location. Geophys J Int [Internet]. 2015 Jan 1;200(1):52–66. Available from: https://doi.org/10.1093/gji/ggu374

4. Karasözen E, Karasözen B. Earthquake location methods. GEM - Int J Geomathematics [Internet]. 2020;11(1):13. Available from: https://doi.org/10.1007/s13137-020-00149-9
5. Pesicek J, Child D, Artman B, Cieślik K. Picking versus stacking in a modern microearthquake location: Comparison of results from a surface passive seismic monitoring array in Oklahoma. GEOPHYSICS. 2014 Nov 1;79:KS61–8.
6. Zhang L, Fang L, Wang W, Lv Z. Seismic phase picking in China Seismic Array using a deep convolutional neuron network*. Earthq Sci [Internet]. 2020;33(2):72–81. Available from: https://www.sciencedirect.com/science/article/pii/S1674451922001252
7. Grigoli F, Scarabello L, Böse M, Weber B, Wiemer S, Clinton JF. Pick- and waveform-based techniques for real-time detection of induced seismicity. Geophys J Int [Internet]. 2018 May 1;213(2):868–84. Available from: https://doi.org/10.1093/gji/ggy019
8. Mousavi SM, Ellsworth WL, Zhu W, Chuang LY, Beroza GC. Earthquake transformer—an attentive deep-learning model for simultaneous earthquake detection and phase picking. Nat Commun [Internet]. 2020;11(1):3952. Available from: https://doi.org/10.1038/s41467-020-17591-w
9. Tiira T, Uski M, Kortström J, Kaisko O, Korja A. Local seismic network for monitoring of a potential nuclear power plant area. J Seismol [Internet]. 2016;20(2):397–417. Available from: https://doi.org/10.1007/s10950-015-9534-8
10. Murillo-Martínez C-A, Agudelo-Zambrano W-M. SENSITIVITY ANALYSIS OF THE BACKPROJECTION IMAGING METHOD FOR SEISMIC EVENT LOCATION . Vol. 11, CT&F - Ciencia, Tecnología y Futuro . scieloco ; 2021. p. 21–32.
11. Ghayournajarkar N, Fukushima Y. Using InSAR for evaluating the accuracy of locations and focal mechanism solutions of local earthquake catalogues. Geophys J Int. 2022 Feb 24;230.
12. Saputra H, Wahyudi W, Suardi I, Anggraini A, Suryanto W. The waveform inversion of mainshock and aftershock data of the 2006 M6.3 Yogyakarta earthquake. Geosci Lett [Internet]. 2021;8(1):9. Available from: https://doi.org/10.1186/s40562-021-00176-w
13. Diehl T, Kissling E, Herwegh M, Schmid SM. Improving Absolute Hypocenter Accuracy With 3D Pg and Sg Body-Wave Inversion Procedures and Application to Earthquakes in the Central Alps Region. J Geophys Res Solid Earth. 2021 Dec 1;126(12).
14. Michelini A, Lomax A. The effect of velocity structure errors on double-difference earthquake location. Geophys Res Lett [Internet]. 2004 May 16;31(9). Available from: https://doi.org/10.1029/2004GL019682
15. Matrullo E, De Matteis R, Satriano C, Amoroso O, Zollo A. An improved 1-D seismic velocity model for seismological studies in the Campania–Lucania region (Southern Italy). Geophys J Int [Internet]. 2013 Oct 1;195(1):460–73. Available from: https://doi.org/10.1093/gji/ggt224
16. Kinnaert X, Gaucher E, Achauer U, Kohl T. Modelling earthquake location errors at a reservoir scale: a case study in the Upper Rhine Graben. Geophys J Int [Internet]. 2016 Aug 1;206(2):861–79. Available from: https://doi.org/10.1093/gji/ggw184
17. Gajek W, Malinowski M. Errors in microseismic events locations introduced by neglecting anisotropy during velocity model calibration in downhole monitoring. J Appl Geophys [Internet]. 2021;184:104222. Available from: https://www.sciencedirect.com/science/article/pii/S0926985120306054
18. Hariyadi H. Agenda-Setting Pembangunan PLTN dan Pencapaian Ketahanan Listrik (Studi Di Jepara Dan Pangkal Pinang). J Ekon Kebijak Publik [Internet]. 2016;(Vol 7, No 2 (2016)):127–42. Available from: http://jurnal.dpr.go.id/index.php/ekp/article/view/594/502
19. Katalog Gempabumi [Internet]. [cited 2021 Aug 19]. Available from: http://repogempa.bmkg.go.id
20. Mangga SA, Djamal B. PETA GEOLOGI LEMBAR BANGKA UTARA, SUMATERA. Pusat Penelitian dan Pengembangan Geologi; 1994.
21. Margono U, Supandjono R, Partoyo E. PETA GEOLOGI LEMBAR BANGKA SELATAN, SUMATERA. Pusat Penelitian dan Pengembangan Geologi; 1995.
22. Gafoer S, Burhan G, Purnomo J. PETA GEOLOGI LEMBAR PALEMBANG,

SUMATERA SELATAN. Pusat Penelitian Dan Pengembangan Geologi; 1995.
23. Mangga SA, Sukardi, Sidarto. PETA GEOLOGI LEMBAR TULUNG SELAPAN, SUMATERA. Pusat Penelitian Dan Pengembangan Geologi; 1993.
24. Baharuddin, Sidarto. PETA GEOLOGI LEMBAR BELITUNG, SUMATERA. Pusat Penelitian dan Pengembangan Geologi; 1995.
25. Franto. Interpretasi Struktur Geologi Regional Pulau Bangka Berdasarkan Citra Shuttle Radar Topography Mission (SRTM) (Interpretation Structure of Regional Geology on Bangka Island with Shuttle Radar Topography Mission (SRTM)). J Promine. 2015;3(1):10–20.
26. Havskov J, Ottemöller L. SeisAn earthquake analysis software. Seismol Res Lett. 1999 Sep;70(5):532–4.
27. Ottemöller L, Voss P, Havskov J. SEISAN EARTHQUAKE SOFTWARE FOR WINDOWS, SOLARIS, LINUX and MACOSX. 2017.
28. Santosa BJ, Salim R. Analisa Pola Bidang Sesar pada Zona Subduksi di Wilayah Selatan Pulau Sumatera dari Event Gempa pada Tahun 2011-2014. J Sains dan Seni ITS. 2014;3(2).
29. Bassin C. The Current Limits of resolution for surface wave tomography in North America. Eos, Trans Am Geophys Union. 2000;
30. Bahri S. STRUKTUR KERAK DI BAWAH WILAYAH INDONESIA BAGIAN BARAT BERDASARKAN DATA RECEIVER FUNCTION. UNIVERSITAS GADJAH MADA; 2020.
31. Mohammed Salih Al-Heety E. New Updated Classification of Shallow Earthquakes Based on Faulting Style. Iraqi J Sci. 2020 Jan 26;103–11.