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# Earthquake Potential Hazard Analysis of Palembang City, Sumatra Island

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**Abstract** - Most of the destructive earthquakes in Sumatra are dominated by thrust mechanisms that occur due to the process of subduction and some earthquakes with strike-slip fault sources such as the Sumatra fault and northwestern Sumatra. Subduction zones along western Sumatra and Sumatran fault zones are active seismic sources of earthquake events. The seismotectonics of South Sumatra can be affected by earthquakes triggered by these seismic sources. In this study, an estimation and analysis of the potential for earthquake hazard curves were carried out in Palembang City due to the influence of subduction zone sources, strike-slip faults, and intermediate to deep earthquake sources. The algorithm of the seismicity smoothing was applied to estimate the seismicity rate for megathrust sources, active faults, and intermediate to deep earthquake sources. The smoothing algorithm is applied to estimate the seismicity rate for megathrust sources, active faults, and intermediate to deep earthquake sources. The earthquake hazard potential curve results showed that the estimated Peak Ground Acceleration (PGA) in the subduction earthquake sources bedrock was greater than the estimated ground shaking due to strike slip fault sources and intermediate to deep earthquake source. To understand better the potential ground shaking, the evaluation of PGA at the surface was then estimated by including the amplification factor. The amplification factor is calculated using the Horizontal-Vertical Spectral Ratio (HVSR) method. Based on the PGA estimated at the surface of 10% probability exceedance level during 50 years, the Palembang City has a potential shaking of around 35 gal, which is likely to be caused by a megathrust earthquake source.

**Keywords**: seismicity smoothing, probability exceedance, Peak Ground Acceleration, amplification, Palembang City



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## Introduction

Indonesia is one of countries that has the highest level of earthquake vulnerability. Therefore, studies on earthquake hazards are needed in Indonesia, especially in densely populated areas. This is evidenced by huge data on earthquake damage in several regions in Indonesia. Most of the destructive earthquakes in Sumatra were dominated by earthquakes with a thrust mechanism that occurred due to the subduction process and strike-slip mechanisms that led to shear faults, such as the Sumatra fault and the northwest Sumatra.

Palembang today is the second-largest city in Sumatra and the ninth-largest city in Indonesia. The city has become a host of several international event, including the 2011 Southeast Asian Games and 2018 Asian Games.

The seismotectonics of South Sumatra can be affected by earthquakes triggered by the above seismic sources. Thus, the Seismic Hazard Analysis (SHA) of Palembang seems to be much needed to understand better how high is the probability of the peak of the ground shaking, not just at the level of base rock but also at the surface.

Earthquake events in the world cannot be predicted precisely. One way to reduce material and life losses due to earthquake events is that building construction must be designed by considering the estimated probability of earthquake acceleration in each region. One way to find out the potential for ground shaking from earthquakes is to analyze the earthquake hazard potential curve or Seismic Hazard Function (SHF), the PGA values plot results, and the Probability Exceedance (PE) of the earthquake occurrence.

In this study, the SHF of Palembang City was analyzed on the basis of the influence of the subduction zone sources, strike-slip faults, and earthquake sources with intermediate to deep hypocentres. The seismicity rate model around the subduction sources and other shallow earthquake sources with the depth of less than and equal to 50 km was based on the integrated source model of Triyoso *et al.* (2020). The strike-slip fault sources were modeled on the basis of seismicity smoothing algorithm (Frankel, 1995). To estimate the seismicity rate around the fault is done by combining the seismicity smoothing of shallow crustal earthquake data around the fault and then weighting by normalized seismicity smoothing of the synthetic seismicity model derived from strike-slip fault data. In case of the intermediate to deep earthquake sources, the earthquake data with the depth of 50 - 150 km and 150−300 km were used, and then smoothed by 75 km correlation distance.

The PGA of 10% probability exceedance level for fifty-year period was analyzed for Palembang City, in which PGA value was obtained by applying several Ground Motion Prediction Equations (GMPE). They are based on Triyoso *et al.* (2020) for subduction sources, Natawidjaja and Triyoso (2007) for strike-slip sources, and the GMPE of Atkinson and Boore (2003) for intermediate to deep earthquake sources. Furthermore, the amplification factor was estimated, and then incorporated into the PGA estimated. The amplification factor was calculated using Horizontal-Vertical Spectral Ratio (HVSR) method of the BMKG data.

## Methods and Materials

In this study, the data used are based on the results of Triyoso *et al*. (2020) for earthquake sources around megathrust, where the A-value model of Gutenberg-Richter (1944) was estimated based on the product of normalized seismic moment rate with mean seismicity smoothing. The correlation distance is 25 km, 50 km, and 150 km of shallow earthquake data of $Mw \geq 5.0$, $H \leq 50$-km of 1963 to 2016.

Active fault data are based on the results of the new revised (simplified) active fault map of the Sumatran Fault Zone (SFZ) according to the PuSGeN Team for Updating Indonesia Seismic Hazard Map with new slip rates from geological and geodetical (GPS) recent studies (Natawidjaja, 2017).

The intermediate to deep earthquake source data are based on PuSGeN (2017) catalog data sorted for depths greater than 50 km to depths of 300 km. The seismic hazard curve was then estimated based on the merging model of megathrust and SFZ sources and the intermediate and deep earthquake models smoothed.

In order to better understand the possible ground shaking level that may occur on the surface, the amplification factor is included in the estimation results of the PGA value in bedrock. The amplification factor was calculated using the vertical-vertical ratio (HVSR) method.

Accelerogram data gained are based on BMKG recording stations spreading over several station positions on Sumatra Island, where one of the them is Palembang (Suwondo, 2020).

**Seismicity Smoothing**

Following the previous study, seismic hazard assessment based on a seismicity smoothing using Gaussian function approach (e.g. Frankel, 1995; Petersen *et al*., 2008; Triyoso and Shimazaki, 2012; Triyoso *et al*. 2020) was implemented. First of all, gridding was done on the area to be studied, then the number ($n_i$) of earthquake events with a magnitude greater than or equal to the reference ($M_{ref}$) was counted in each grid. The quantity counting of $n_i$ represents the maximum likelihood estimate of $10^a$ or the earthquake A-value with a magnitude above $M_{ref}$ in each grid (Bender, 1983). The $n_i$ values in each grid were then smoothed spatially by applying a Gaussian function using a correlation distance *c*. For each grid of *i*, the smoothed value was obtained from:

$$\tilde{n}_i = \frac{\sum_{j} n_i e^{-\Delta^2_{ij}/c^2}}{\sum_{j} e^{-\Delta^2_{ij}/c^2}} \quad ..............................(1)$$

in which:

$n_i$ is normalized to preserve the total number of events,

$\Delta_{ij}$ is the distance between the *i*-th and *j*-th cells,

*c* is the correlation distance.

In equation (1), the sum is taken over cell *j* within a distance of 3c from cell *i*.

**Occurrence Rate Function**

Following the theory of the earthquake occurrence, the rate function for a particular cell, $v_i$ ($\geq M_{ref}$), could be formulated by:

in which:

$$v_i(\geq M_{ref}) \approx \frac{N_i}{T} \quad ..................................(2)$$

$N_i$ is the number of earthquake with magnitude $\geq M_{ref}$ in cell *i,*

*T* is the length of record,

$v_i$ represents the $10^a$ of the earthquake with a magnitude greater than or equal to $M_{ref}$.

The $M_{ref}$ can be decided from the view point of magnitude completeness ($M_c$) or larger. It is implied that applying the Gaussian function to smooth the seismicity is accepting the $10^a$ by equation (2). Furthermore, by substituting $10^a$ of equation (2) in equation (1), the following equation may be obtained:

$$v_i(\geq \text{m}) \approx \frac{\tilde{n}_i(\geq M_{ref})}{T.b\,ln(10)} 10^{-bm}(1-10^{b(m-M max)}) \quad ...(3)$$

in which:

$v_i$ ($\geq M_{ref}$) expressed the smoothed value in each grid *i* for earthquake numbers greater than or equal to the reference magnitude during the time interval *T*,

*b* is the uniform *b*-value.

$M_{max}$ ~ 9.0 is used in this study in case of shallow crustal and subduction earthquake sources, and $M_{max}$ ~ 8.0 in case of the intermediate to deep earthquake sources.

**Hazard Calculation: Probability of Exceedance (PE)**

The annual probability exceedance of peak horizontal ground motion (PGA or PGV) *u* at a site due to events at a particular cell k under the Poisson distribution is given by:

$$P(u \geq u_0) = P_k[m \geq m(u_0, D_k)] = 1 - e^{\{-v_i[\geq m(u_0,D_k)]\}} \quad ..(4)$$

where:

$P_k(m \geq m\ (u_o,\ D_k))$ is the PE of an earthquake in the grid of $k^{th}$

$m\ (u_o,\ D_k)$ is the quantity of magnitude of $k^{th}$ source cell that would produce a peak ground motion of $u_o$ or larger at the site,

$D_k$ is the distance between site and source cell.

The function $m(u_o, D_k)$ is the GMPE. The probability distribution of peak ground motion at the site was determined by integrating the influences of the surrounding source cells, i.e.:

$$\text{P}(\text{u} \geq \text{u}_0) = 1 - \pi\, [1 - \text{P}_\text{k}(\text{u} \geq \text{u}_0)] \quad ......................(5)$$

By substituting the GMPE, the following equation could be obtained:

$$P(u \geq u_0) = 1 - \pi e^{\{-v_i[\geq m(u_0,D_k)]\}} = 1 - e^{-\sum v_i[\geq m(u_0,D_k)]} \quad ..(6)$$

which gives the annual exceedance probability of particular PGA or PGV. For specific time duration *T* the probability of exceedance is given by:

$$P(u \geq u_0) = 1 - [1 - P(u \geq u_0)]^T = 1 - e^{\{-T \sum v_i[\geq m(u_0,D_k)]\}} \quad ..(7)$$

The annual PE of the specified ground motions was calculated by applying equation (6) for each grid. For a specified time duration *T*, the probability of exceeding specified ground motions was computed using equation (7).

**Ground Motion Prediction Equation (GMPE)**

In constructing the probabilistic seismic hazard map expressed by peak ground motion defined as PGA or PGV, the GMPE is needed in terms of PGA or PGV as a function of magnitude and distance. The GMPEs are based on the result summarized in Triyoso *et al*. (2020) in which the GMPEs of Zhao *et al*. (1997) and Atkinson and Boore (2006) were used for subduction sources, (Natawidjaja and Triyoso, 2007). The GMPE of Fukushima and Tanaka of 1990 is updated with the GMPE of Fukushima and Tanaka of 1992, for strike-slip sources. While GMPE of Atkinson and Boore (2003) was applied for intermediate and deep earthquake sources.

**Horizontal-to-Vertical Spectral Ratio (HVSR or H/V)**

The Horizontal-to-Vertical Spectral Ratio (HVSR or H/V) method is one of methods for obtaining the bottom-surface information of a single station measurement on the surface of the earth that was originally used to examine the risk of earthquake in Japan. The acquisition of data on this method requires a three-component station that serves to perform a spectrum comparison of the Fourier horizontal and vertical components. The assumption used in this HVSR method is the H/V ratio value in bedrock equals one. The assumption was derived because the amplitude of waves that propagate towards the vertical and horizontal direction was of equal value. Thus, the HVSR formula can be written in the equation:

$$H/V = A_H/A_V \quad ..........................................(8)$$

in which:

$A_H$ is Fourier spectrum of the horizontal component of accelerogram data,

$A_V$ is Fourier spectrum of the vertical component of accelerogram data.

Mucciarelli and Galipolli (2004) conducted a comparative review of HVSR methods using Rayleigh waves and noise. The analysis was conducted to five hundred and more HVSR results for three stations being in sediment and one station being in the base rock. The conclusion of the review of HVSR analysis by using noise and earthquake waves shows the same results. Other studies conducted in Los Angeles Basin used Rayleigh waves and body waves. The results of the study showed Rayleigh waves gave better amplification information in the sedimentary basin area compared to the ones using only the body wave (Bowden and Tsai, 2017). In this study, the amplification was calculated based on the frequency band of 0.3 - 0.7 Hz. The use of this frequency range is based on Bowden and Tsai (2017). Incorporating the amplification into PGA was done by multiplying the SHF with the amplification factor. This implies that the PGA estimated at base rock was converted to the PGA at the surface.

## Results and Analyses

A-values for active fault data were modelled by integrating shallow earthquake data from PuSGeN 2017 ($M_w \geq 5.0$, $H \leq 50$ km of the years 1963 to 2016) around the active fault zone, and synthetic catalog data were constructed from active fault distribution data. The algorithm for constructing synthetic catalog models is based on Triyoso and Shimazaki (2012), which in this study modelled earthquake epicentre positions were distributed uniformly along the active fault position for each interval of about 10-km distance. Subsequent synthetic epicentre distribution data were smoothed with a distance correlation of 25 km. For shallow earthquake data around the active fault zone, the application of the seismicity smoothing algorithm is based on the study of Frankel (1995) by applying smoothing with a correlation distance of 75 km. The integration between the two models was done by weighting the A-value model from the earthquake catalog with normalized smoothed seismicity obtained from active fault data. The results of the model integration can be seen in Figure 1a. Next, the two models in Figure 1 (a and b) were combined to produce a shallow seismicity rate and a regional b-value model estimated based on the combined model area determined as shown in Figure 2a. The area for determining the b-value is based on the shallow earthquake catalog ($M_c \sim 4.7$, $H \leq 50$ km of the years 1963 to 2016) in radius of 500 km with Palembang City as the centre. The b-value obtained is around 0.972 (Figure 2b).

In case of the intermediate and deep earthquake data, the application of the seismicity smoothing algorithm is based on Frankel (1995) by applying smoothing with a correlation distance of 75 km of the earthquake catalog of PuSGeN 2017 ($M_w \geq 5.0$, $50 < H \leq 150$ km and $150 < H \leq 300$ km of the years 1963 to 2016), and by adding the uniform background zone. Developing the A-values was done by combining the smoothed seismicity model with uniform background zone with the weight of 0.75 and 0.25 (Triyoso and Shimazaki, 2012). The area for determining the b-value for the intermediate and deep earthquake catalog is similar with the above merging model in which the used earthquake catalog is $M_c \sim 4.6$, $50 < H \leq 300$ km of the years 1963 to 2016. The b-value obtained is around 1.23. Figure 3 shows the merging model of seismicity rate based on smoothed seismicity of the intermediate and deep earthquake sources (Figure 3a) and the b-value (Figure 3b).

Figure 4 shows the station distribution in which the amplification factor is calculated using

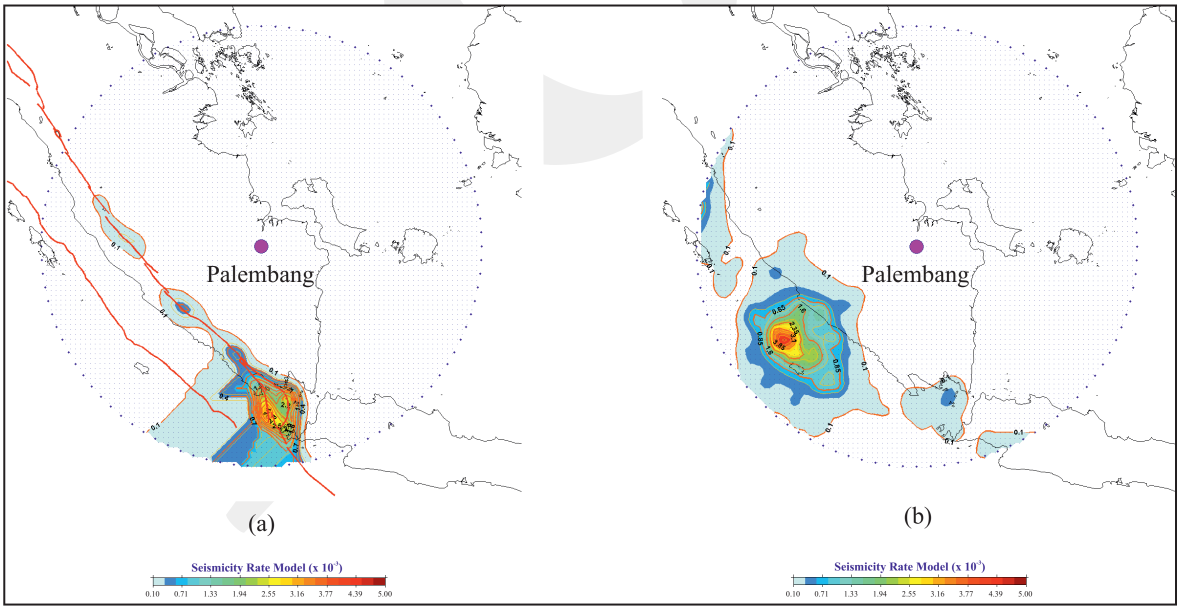


Figure 1. (a) The A-value model based on Triyoso *et al*. (2020), estimated by weighting the normalized seismic moment rate with mean seismicity smoothing of shallow earthquake data. The seismicity smoothing correlation distance is 25 km, 50 km, and 150 km, and (b) A-values for active fault data modeled by integrating shallow earthquake data from PUSGEN 2017 around the active fault zone and synthetic catalog data constructed from active fault distribution data. The algorithm for constructing synthetic catalog models is based on Triyoso and Shimazaki (2012). In this study, modeled earthquake epicenter positions are distributed uniformly, and the active fault position for each interval 10-km distance. Subsequent synthetic epicenter distribution data was smoothed with a distance correlation of 25km. For shallow earthquake data around the active fault zone, the seismicity smoothing algorithm application is based on a 75km radius. Integration between the two models is done by weighting the A-value model from the earthquake catalog with normalized smoothed seismicity obtained from active fault data.

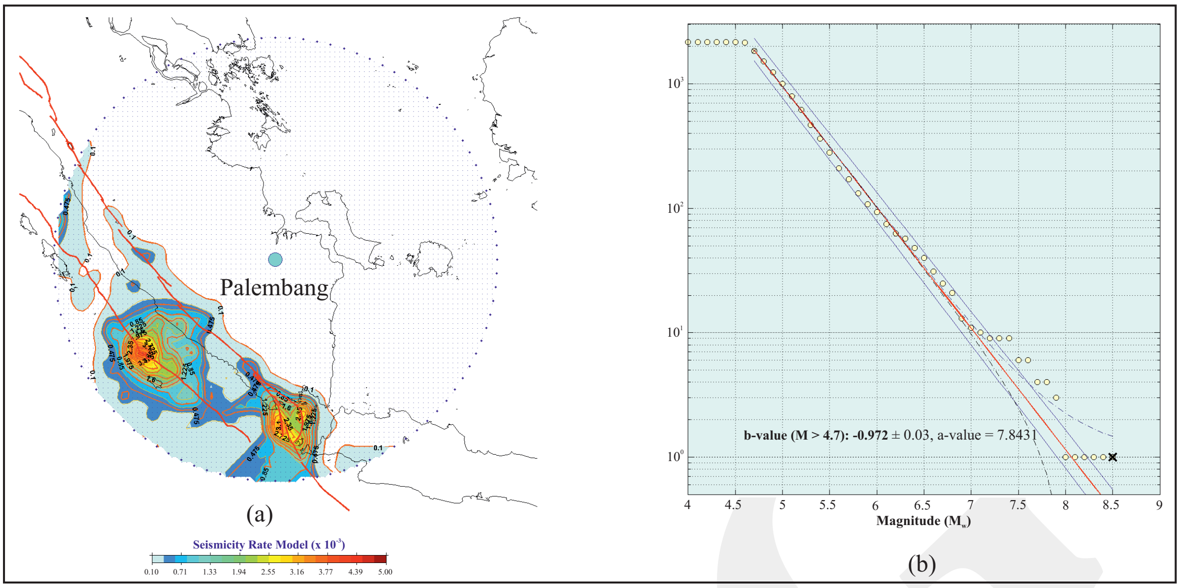


Figure 2. (a) The combined model that is developed based on megathrust source model and active fault model; and (b) the b-value that is based on the shallow earthquake catalog ($M_c$ ~ 4.7, H ≤ 50km, 1963-2016) which is within a 500km radius with the center of the city is Palembang.

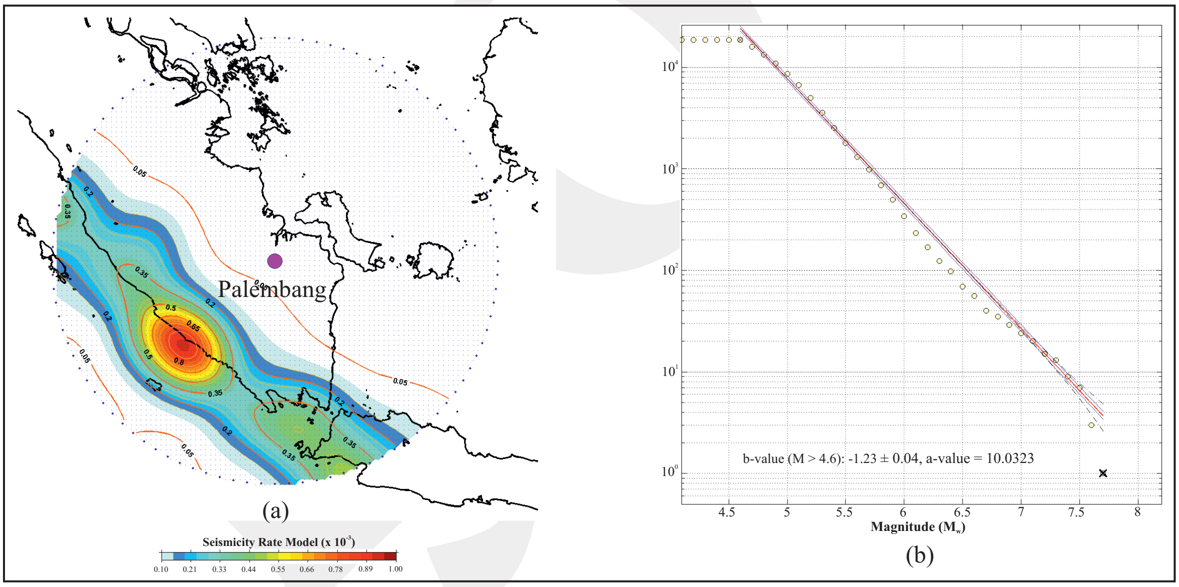


Figure 3. (a) The seismicity rate model based on smoothed seismicity of the intermediate and deep earthquake sources and (b) the b-value to develop the A-values is done by a combination of the smoothed seismicity model of earthquake data ($M_w$ ≥ 5.0, 50 < H ≤300km of the years 1963 to 2016) with a uniform background zone with the weight of 0.75 and 0.25 (Triyoso and Shimazaki, 2012). The earthquake catalog ($M_c$ ~ 4.6, 50 < H ≤300km of the years 1963 to 2016) is used to estimate the b-value in which the area is within a 500km radius with the center of the city is Palembang.

the Horizontal-Vertical Spectral Ratio (HVSR) method of the accelerogram of the BMKG data. The amplification factor was calculated based on recorded data at Palembang station that is about 2.7 (Suwondo, 2020).

Figure 5 shows the result of SHF of Palembang City based on the shallow earthquake sources with amplification included (a) and SHF based on intermediate and deep earthquake sources. The results showed that the estimated peak ground

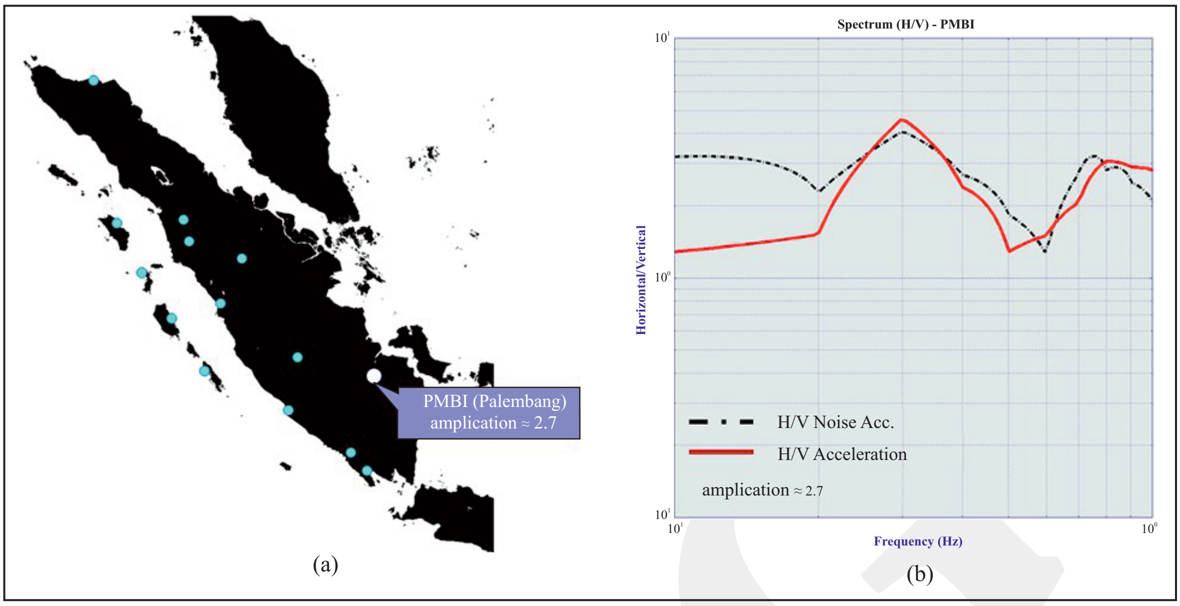


Figure 4. (a) The distribution of the station in which the amplification factor is calculated using Horizontal-Vertical Spectral Ratio (HVSR) method of the accelerogram of the BMKG data and (b) the result of the amplification factor calculated based on recorded data at Palembang station (PMBI) is about 2.7.

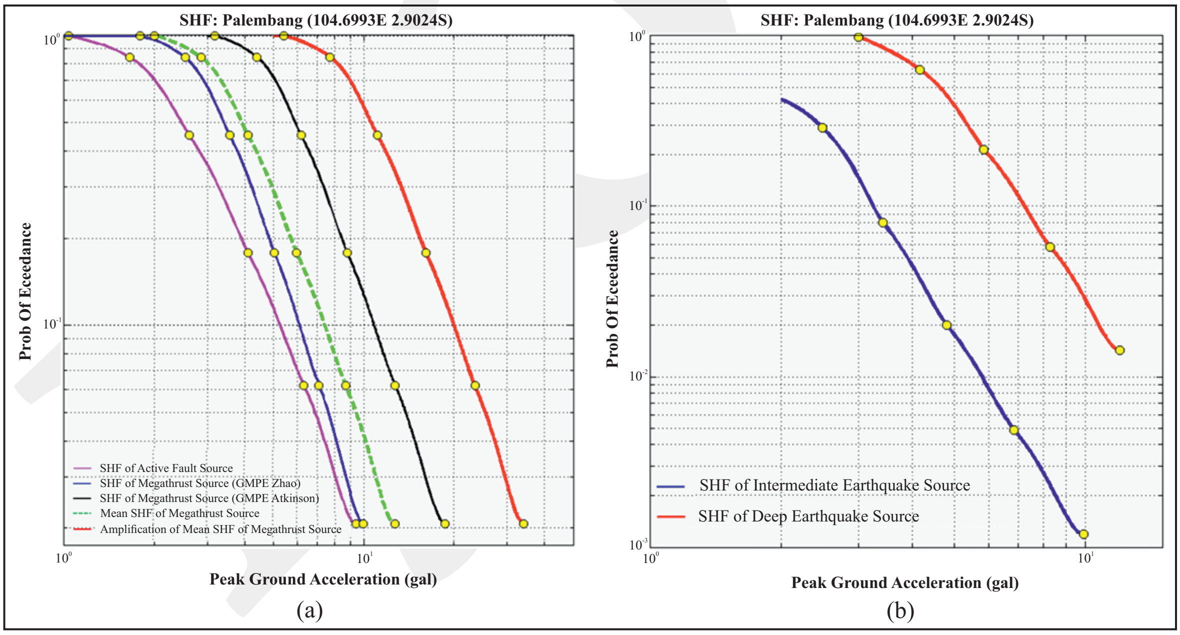


Figure 5. (a) The result of the SHF of Palembang City based on the shallow earthquake sources with amplification included and (b) SHF based on intermediate and deep earthquake sources. The SHF is estimated based on the median PGA. The results showed that the estimated PGA at the bedrock of subduction earthquake sources was more significant than the estimated PGA due to strike-slip fault sources and deeper earthquake sources.

acceleration (PGA) at the bedrock of subduction earthquake sources was more significant than the estimated ground shaking due to strike-slip fault sources and deeper earthquake sources. The potential ground shaking at the surface was then estimated by including the amplification factor based on the HVSR method. Based on the PGA estimated at the surface of 10% probability exceedance level during fifty years, the Palembang City has a potential ground shaking of around 35 gal, which is likely to be caused by a megathrust earthquake source.

## Discussion and Conclusions

The earthquake hazard function against megathrust, active fault, and intermediate to deep earthquake sources of the Palembang City, Sumatra Island was carried out by realizing the SHF. The SHF showes that the estimated PGA at the bedrock subduction earthquake sources was greater than the estimated ground shaking due to strike-slip fault sources and intermediate to deep earthquake sources.

Since Palembang today is the second largest city in Sumatra and the ninth largest city in Indonesia in which the infrastructure, population, and investment would grow in the near future, the detailed evaluation of level ground shaking caused by earthquake need to be evaluated in more detail by incorporating the probability level of the ground shaking at the surface.

The potential ground shaking has been incorporated at the surface by including the amplification factor based on the HVSR method. Based on the PGA estimated at the surface of 10% probability exceedance level during 50 years, the Palembang City has a potential ground shaking of around 35 gal, which is likely to be caused by the megathrust earthquake source.

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## References

Atkinson, G.M. and Boore, D.M., 2003. Empirical ground-motion relations for subduction-zone earthquakes and their application to Cascadia and other regions. *Bulletin of the Seismological Society of America,* 93(4), p.1703-1729. DOI:10.1785/0120020156

Atkinson, G.M. and Boore, D.M., 2006. Earthquake ground-motion prediction equations for Eastern North America. *Bulletin of the Seismological Society of America,* 96 (6), p.2181-2205. DOI:10.1785/0120050245

Bender, B., 1983. Maximum likelihood estimation of b values for magnitude grouped data. *Bulletin of the Seismological Society of America,* 73, p.831-851.

Bowden, D.C. and Tsai, V.C., 2017. Earthquake Ground Motion Amplification for Surface Waves. *Geophysical Research Letters,* 44, p.121-127. DOI:10.1002/2016gl071885

Frankel, A., 1995. Mapping seismic hazard in the Central and Eastern United States. *Seismological Research Letters,* 66 (4), p.8-21.

Fukushima, Y. and Tanaka, T., 1990. A New Attenuation Relation for Peak Horizontal Acceleration of Strong Earthquake Ground Motion in Japan. *Bulletin of the Seismological Society of America*, 80 (4), p.757-783.

Fukushima, Y. and Tanaka, H., 1992. The revision of "A new attenuation relation for peak horizontal acceleration of strong earthquake ground motion in Japan". *Abstracts The Seismological Society of Japan, Fall Meeting,* B18 (in Japanese).

Gutenberg, B. and Richter, C.F., 1944. Frequency of earthquake in California. *Bulletin of the Seismological Society of America,* 34, p.185-188.

Jetstar, 2018. *Palembang, Indonesia Panduan Wisata, Aktivitas di Palembang*. www.jetstar.com (in Indonesian).

Mucciarelli, M. and Gallipoli, M.R., 2004. The HVSR Technique from Microtremor to Strong Motion: Empirical and Stastitical Consideration. *13$^{th}$ World Conference on Earthquake Engineering Canada*.

Natawidjaja, D.H. and Triyoso, W., 2007. The Sumatran Fault Zone - From Source To Hazard. *Journal of Earthquake and Tsunami,* 1 (01), p.21-47. DOI:10.1142/s1793431107000031

Natawidjaja, D.H., 2018. Updating active fault maps and sliprates along the Sumatran Fault Zone. Indonesia. *IOP. Conference Series Earth and Environmental Science,* 118-012001. DOI:10.1088/1755-1315/118/1/012001

Petersen, M., Harmsen, S., Mueller, C., Haller, K., Dewey, K., Luco, N., Crone, A., Lidke, D., and Rukstales, K., 2007. Documentation for the Southeast Asia Seismic Hazard Maps. *Administrative Report September 30, 2007*, U.S. Department of the Interior, U.S. Geological Survey. DOI:10.3133/70045119

PuSGeN (Pusat Studi Gempa Nasional), 2017. *Peta Sumber dan Bahaya Gempa Indonesia Tahun 2017*. Jakarta: Kementerian Pekerjaan Umum dan Perumahan Rakyat (in Indonesian). DOI:10.25105/jti.v6i2.1540

Suwondo, A., 2020. *Analisa Fungsi Seismik Hazard dan Amplifikasi di Pulau Sumatra. Master Thesis*, Master Study Programme of Geoscience, Bandung Intitute of Technology (in Indonesian).

Triyoso, W. and Shimazaki, K., 2012. Testing Various Seismic Potential Models for Hazard Estimation Against a Historical Earthquake Catalog in Japan. *Earth Planets Space,* 64, p.673-681. DOI:10.5047/eps.2011.02.003

Triyoso, W., Suwondo, A., Yudistira, T., and Sahara, D.P., 2020. Seismic Hazard Function (SHF) study of coastal sources of Sumatra Island: SHF evaluation of Padang and Bengkulu Cities, *Geoscience Letters,*7 (2), 77pp. DOI: 10.1186/s40562-020-00151-x.

Zhao, J.X., Dowrick, D.J., and McVerry, D.H., 1997. Attenuation of peak ground acceleration in New Zealand earthquakes. *Bulletin of New Zealand National Society for Earthquake Engineering,* 30 (2), p.133-158. DOI:10.5459/bnzsee.30.2.133-158