Deterministic seismic hazard analysis for assessing earthquake hazard in Sungai Penuh and Kerinci Regency

Ichy Lucya Resta*, Devi Putri Apriliyani, Nasri MZ, Juventa and Ira Kusuma Dewi

Department of Geophysical Engineering, Faculty of Science and Technology, Universitas Jambi, Jl. Jambi – Muara Bulian Km 15, Jambi 36122, Indonesia

*ichylucyaresta@gmail.com

Abstract. Assessment of seismic hazard is necessary in land use planning and hazard mitigation. It leading to subdivided a region into sub-region which different safeguards to prevent damage in case an earthquake is occurred. The quantitative assessment of seismic hazard is carried out in Sungai Penuh and Kerinci Regency using deterministic seismic hazard analysis (DSHA) method. Earthquake scenario of Mw 7 at depth of 10 km by Siulak fault source were used for analysis to estimate the ground motion over the investigated areas. The resulting DSHA map reveals high seismic hazard level in terms of PGA 49.8 – 71.9 gal alongside the active Siulak fault zones. The intensity of the region are dominated by VII-VII of MMI scale which puts in the high hazard zone.

1. Introduction
The Siulak fault is one of active segment defined as a part of Sumatran Fault Zone (SFZ) [1; Fig.1]. These fault zones accommodates part of the oblique convergence of the subduction between the Indo-Australian and Eurasian plates are associated with Cenozoic Period with 1650-km-long dextral strike-slip fault zone [2]. The segment is cross over Kerinci and Sungai Penuh regency which is a valley filled with volcanic material by Kerinci Volcano and surrounding volcano [3]. In 1995, an earthquake of Mw 7.0 produced ground shaking which killed approximately 84 people and destroy 17,670 houses in this area [4]. Seismic activity in this area approved by later seismicity as earthquake occurred in 1999. As this area predicted still capable of generating earthquake and violent ground shaking caused by earthquakes can lead to massive fatalities, it is necessary that seismic hazard assessment is undertaken in this area to predict occurred ground motion due to potential earthquakes in the future.

The aim of present study is to obtained the ground motion value over the investigate area using seismological data through deterministic seismic hazard analysis (DSHA) methodology which already success in mapping seismic hazard in several area [5, 6, 7, 8, 9, 10, 11]. Available seismicity catalogues, geological data, and one or more earthquakes scenario are used to estimate ground motion value over the investigated area. An understanding of ground motion which is related to seismic events will provide information for decision-making for earthquake mitigation, land use and infrastructure. We expect that engineers will be able to use our result as consideration of seismic design maps to improved building design and construction.
2. Geology Regional
Kerinci is located in the depression zone and is situated in the 35 km long Siulak segment [1] with physiography consist of Bukit Barisan and Sumatra Fault zones [12]. Siulak Fault segment is source of seismic activity in this area. Study area consist of 16 stratigraphy units, while Quaternary volcanic rocks is dominated (Figure 2).

3. Deterministic Seismic Hazard Analysis (DSHA)
Deterministic seismic hazard analysis (DSHA) [5, 6] and probabilistic seismic hazard analysis (PSHA) [15] are two kind of seismic hazard analysis which being use recently. DSHA were investigated in this...
study instead. The main objective of this analysis were to reveal a worst scenario for critical seismic hazard in the investigated area as engineering consideration to unpredicted earthquake events. DSHA requires the determination of expected maximum magnitude or maximum credible earthquake that may occurred which creates the largest hazard for the site [11, 16]. To evaluate ground shaking at given site, an empirical strong ground motion attenuation model is employed. The shortest source-to-site distance is then selected and the worst case scenarios for specific areas determined [11].

The assumption a worst case scenario for each earthquake source which used in analysis give information about the worst seismic hazard level that can be occurred. As suggestion, Krinitzsky [7] defined DSHA for designing critical structures consideration base on PGA on site, such as the nuclear power plants and large dams. Also need to considered, DSHA limitation which is not considering uncertainty and probability of earthquake events to be happened over the investigated territory [17].

4. Data and Method
Deterministic seismic hazard analysis was being used to expect maximum ground motion in Kerinci and Sungai Penuh regency. The conventional DSHA is associated with single controlling seismic sources to predict ground motion [16]. The ground motion will describe in term peak ground acceleration (PGA) and spectral acceleration (SA) for 0.1 s, 1.0 s and 3.0 s. To describe this area interest in term of intensity which is related to seismic events, we used MMI scale base on Worden classifications [18]. We obtained parameters necessary to determine earthquake potential from earthquake catalog records in area interest. The earthquake scenario of Mw 7.0 at 10 km depth in 1995 by Siulak fault [19] is used in this study. Shake map by USGS being used to calculate PGA. Meanwhile, the timed-averaged shear-wave velocity to 30 m depth (Vs30) data extracted from USGS is distributed in a map to confirm DSHA results.

5. Result and Discussion
Seismic hazards expressed in Peak ground acceleration (PGA). As observed for PGA map in Fig. 4a, the values decreasing from center to surrounding area. It reveals an extremely high hazard level along the active fault zones as these results does not considered the activity rate of earthquake occurrence. The figure clearly shows that central area where the active fault laid on is more susceptible to higher seismic hazard.

PGA calculated for the credible earthquake scenario ranges from 16 gal in most of areas far from Siulak faults to 71.9 gal alongside the active faults (Fig. 4a). PGA can be convert to intensity level to describe seismic hazard. Intensity of these area can be described by MMI levels to show how potential damage may be occurred due to an earthquake event. It observed that Sungai Penuh and Kerinci regency was VI to VIII by MMI level. The potential damage range from light to moderate (Table 1). District of 16 to 22 gal in term of PGA to be predicted having light potential damage, meanwhile district of 22-45 gal in term of PGA would have moderate potential damage. The moderate/heavy potential damage may occurred in district of 45-71.9 gal in term of PGA.

The earthquake prone areas are in central to eastern Kayuaro Barat; central of Gunung Kerinci, Siulak and Bukit Kerman; northern of Gunung Raya; western of Kayuaro, Danau Kerinci, Air Hangat Timur, Sitinjau Laut; and eastern of Air Hangat Barat, Sungai Penuh, Depati Tujuh, and Keliling Danau. Conversely, almost all side of district which far away from Siulak fault have low seismic hazard potential (Gunung Tujuh, western Sungai Penuh, eastern of Siulak Mukai and Air Hangat, and Batang Merangin). Sungai Penuh, as a center of major activity, is dominated by area is placed in the seismic zone VII, where mainly the PGA value varies for 22 gal to 40 gal. This region show high seismic hazard with PGA value decreasing from east to west of Sungai Penuh. The region in eastern of Sungai Penuh and tip of southwestern region have contras PGA range value. It shows the east area is placed in the seismic zone VIII with PGA value range from 40 to 71 gal, meanwhile for tip of the southeast area in
Figure 3. Hazard curves plot between PGA values (gal) vs distance from earthquake source (km). It reveals the distance contribution to PGA value distribution by DSHA.

Figure 4. Maps showing of PGA, SA 0.1 s, SA 1.0 s, and SA 3.0 relative contribution from event of $M_w$ 7.0 from Siulak fault, respectively. White star denotes source of event [19].
the seismic zone VI with PGA value range from 16 to 22 gal. It is observed that source that contributes to high PGA values in this area was Siulak fault segment. The same trend were obtained in Peta Bahaya Gempa Indonesia 2017 [19].

Figure 3 presents the hazard curves in terms of PGA against distance from earthquake source, which clearly highlights that the hazards in central area (over Kerinci valley concentrate) being the highest, follow by the surrounding area. The curve provide information regarding distance parameter have a major contribution to PGA value resulted from DSHA. The information from the hazard curve is reflected in all of DSHA maps.

Although the SA values differ, all of SA maps exhibit a similar pattern in that the SA values gradually decrease from Siulak fault to surrounding area cover up Sungai Penuh and Kerinci regency (Fig. 4b, 4c, 4d). SA maps mainly used for engineering consideration. Once again, higher values were observed for areas alongside Siulak fault due to their location closer to the seismically active Sumatra region. For the current study, it should be note that these hazards are calculated based on worst case scenario for Siulak fault source.

---

**Figure 5.** The timed-averaged shear-wave velocity to 30 m depth (Vs30) relative distribution

The timed-averaged shear-wave velocity to 30 m depth (Vs30) map, with the range shear-wave velocity being 200 ms\(^{-1}\) to 794 ms\(^{-1}\), showed good agreement compared to PGA map around Siulak fault area (Fig. 5). Even though the DSHA indicated that Siulak Mukai and Gunung Tujuh district is less susceptible to higher hazard in comparison to the district alongside fault zone, the Vs30 map suggest that the hazard at both district to be highest. This indicate that seismic hazard analysis by DSHA method need to be combine with another method for the best result agreement. The same recommendation has been point out in others study [20, 21].
### Table 1. Hazard level in term intensity in different MMI level base on [18] classification in Sungai Penuh and Kerinci Regency

| Perceived shaking | Potential damage | Peak Ground Acceleration (cm/s²) | Peak Velocity (cm/s) | Intensity |
|-------------------|------------------|---------------------------------|---------------------|-----------|
| Strong            | Light            | 16-22                           | 9.6                 | VI        |
| Very strong       | Moderate         | 22-40                           | 20                  | VII       |
| Severe            | Moderate/Heavy   | 40-71                           | 41                  | VIII      |

### 6. Conclusions

These paper presents an overall SHA in terms of PGA for Sungai Penuh and Kerinci regency using DSHA which historical point sources were modelled. The potential seismic hazard is in good agreement with Vs30 distribution around Siulak fault zone. The DSHA for critical case scenario indicated that the hazard across Sungai Penuh and Kerinci regency in terms of PGA ranges from 16 to 71.9 gal while the highest PGA occurred in areas alongside Siulak fault. Similarly, the SA maps showed that the response have highest value alongside Siulak fault. However, it need to mention that the current study only focused on PGA and SA results without taking into consideration soil amplification and site effect which possibly leads to an inadequate estimate. Therefore, combining some method to predict seismic hazard is considered necessary for this area to give best analyses in mapping seismic hazard.

### References

[1] Natawidjaya D.H Updating active fault maps and sliprates along the Sumatran Fault Zone, Indonesia Conf.Series: Earth and Enviromental Science **118**. Pp 1-10

[2] Sukmono S, Zen M T, Hendrajaya L, Kadir W G A, Santoso D and Dubois J 1997cFractal pattern of the Sumatra fault seismicity and its possible application to earthquake prediction Bull. Seismol. Soc. Am. **87** (6) pp 1685–90

[3] Poedjopradjitno S 2012 Morfotektonik dan potensi Bencana Alam di Lembah Kerinci Sumatera Barat berdasarkan analisis potret udara J. Sumb. Day. Geol **22** pp 101-113

[4] Kurniawan L, Naryanto H S and Santoso E W 1997 Alami nomor 3 pp 32-35

[5] Costa G, Panza G F, Suhadole P and Vaccari F 1992 Zoning of the Italian region with synthetic seismograms computed with known structural and source information Proceeding of 10th World Conference on Earthquake Engineering Madrid Spain pp 435-438

[6] Costa G, Panza G F, Suhadole P and Vaccari F 1993 Zoning of italian territory in terms of expected peak ground acceleration derived from complete syntetic seismograms J.Appl. Geophys. **30** pp 149-160

[7] Krinitzsky E L 1995 Deterministic versus probabilistic seismic hazard analysis for critical structure Eng. Geol **40** pp 1-7

[8] Aoudia K, Vaccari F, Suhadole P and Meghraoui M 2000 Seismogenic potential and earthquake hazard assessment in the Tell Atlas of Algeria J. Seismol. **4** pp 79-98

[9] Bommer J J 2002 Deterministic vs probabilistic seismic hazard assessment: an exaggerated and obstructive dichotomy J. of Earthquake Eng. **6**:S1 pp 43-73

[10] Moratto L, Orlecka-Sikora B, Costa G, Suhadole P, Papaioannou Ch and Papazachos CB 2007 A deterministic seismic hazard analysis for shallow earthquakes in Grace Tectonophysics **442** issue 1-4 pp 66-82

[11] Pailoplee S, Sugiyama Y and Charusiri 2009 Deterministic and probabilistic seismic hazard analyses in Thailand and adjacent areas using active fault data Earth Planet SP **61** pp 1313-1325

[12] Bemmelen R W van 1949 The Geology of Indonesia vol 1A (The Hague: Government Printing Office)

[13] Kusnama Parrdede R, Mangga S A and Sidarto 1992 Geological Map of the Sungai Penuh and Ketahun Quadrangle, Sumatra Scale 1:250.000 (Bandung, Indonesia: Pusat Penelitian dan
[14] Rosidi H MD, Pietro S T, Pendowo B, Gafoer S and Suharsono 1996 \textit{Geological Map of the Painan and northeastern Part of Muarasiberut Quadrangle, Sumatra Scale 1:250.000} (Bandung, Indonesia: Pusat Penelitian dan Pengembangan Geologi)

[15] Cornell C A 1968 Engineering seismic risk analysis \textit{Bull. Seismol. Soc. Am.} \textbf{58} pp 1583-1606

[16] Huang D, Wang J P, Brant L and Chang S C 2012 Deterministic seismic hazard analysis considering non-controlling seismic sources and time factors 7520. 55-557. 10.1007/978-3-642-33362-0_42

[17] Kramer, S.L 1996 \textit{Geotechnical Earthquake Engineering} (Upper Saddle River, New Jersey: Practice Hall Inc.) p 643

[18] Worden, C.B., M.C. Gerstenberger, D.A. Rhoades, D.J. and Wald 2012 Probabilistic relationships between ground-motion parameters and modified mercalli intensity in California \textit{Bull. Seismol. Soc. Am.} \textbf{102} issue 1 pp 204-221

[19] Pusat Studi Gempa Nasional (Pusgen) 2017 Peta sumber dan Bahaya Gempa Indonesia 2017 (Pusat Litbang Perumahan dan Permukiman, Kemen PUPR)