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ESTIMATION MODEL PEAK GROUND ACCELERATION AT BEDROCK AND SURFACE OF THE PASAMAN BARAT EARTHQUAKE ON FEBRUARY 25, 2022 $M_w 6.1$

Furqon Dawam Raharjo[1,2], Syafriani*[1], Suaidi Ahadi[1]
[1] Departement of Physics, Faculty of Mathematics and Natural Sciences, Universitas Negeri Padang, Indonesia
[2] Indonesian Meteorology, Climatology and Geophysics Agency, Indonesia
*syafri@fmipa.unp.ac.id

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ABSTRACT

The earthquake occurred on February 25, 2022, 01:39:29 UTC in Pasaman Barat, West Sumatra Province. It has a moment magnitude of Mw6.1 and produces strong ground motion. That earthquake caused many buildings to be damaged. The peak ground acceleration (PGA) represents its level ground acceleration in bedrock, and peak surface acceleration (PGA_m) describes the acceleration value on the surface. Information peak ground acceleration at bedrock and surface values are important in describing the level of damage due to earthquake events. The purpose of this study is to estimate the peak ground acceleration at bedrock and surface for the Pasaman Barat earthquake. $M_w 6.1$. The peak ground acceleration values at bedrock and surface were determined using Boore's (1997) GMPE attenuation equation and amplification factors based on the soil type classification and the peak ground acceleration value in bedrock at period T = 0 s. This study uses main earthquake information data such as magnitude, hypocenter distance, and shear wave velocity model at a depth of 30 meters from the USGS. This study showed that peak ground acceleration at bedrock and surface in the Pasaman Barat earthquake ranged between 0.066 - 0.345 g and 0.223 - 0.627 g. Several areas were damaged by the earthquake, such as Kajai, Rimbo Panti, Malampah, and Tigo Nagari with peak ground acceleration values at bedrock and surface are around 0.115 - 0,345 g and 0.423 - 0.627 g, respectively, and was dominated by type site class moderate soil (SD) based on Vs30 data from the USGS model.

Keywords: Boore (1997); GMPE; PGA at bedrock and surface

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INTRODUCTION

Pasaman Barat is an area that is very prone to earthquake disasters because it is controlled by the Sumatra megathrust subduction zone and the Sumatra active fault system zone [1-16]. The Sumatra megathrust subduction zone is influenced by active tectonic plates, namely the Indo-Australian plate and the Eurasian plate [13-16]. The Indo-Australian plate subducts at a very shallow depth and moves obliquely to the Eurasian plate [16]. The implications of the tectonic activity of the Indo-Australian and Eurasian plates in the subduction zone often cause earthquakes, so the island of Sumatra is considered one of the active tectonic regions in the world [1]. The Sumatra active fault system is an active onshore fault formed by the movement of the oblique subduction zone of the Indo-Australian plate and the Eurasian plate [1-16]. The movement pattern of Sumatra's active faults is a lateral strike-slip fault with a length of 1900 km stretching from Aceh to Semangko Bay in Lampung and is segmented into 19 active fault segments [16]. Especially in Pasaman Barat, it is traversed by the Angkola, Barumun, Sianok, and Sumpur segments, and these four active fault segments are one of the earthquake sources whose existence we should be aware of and become a threat because they pass through densely populated areas (Figure 1). [20] has estimated the maximum magnitude for the four segments, including, Sianok segment ~M_w7.4, Sumpur ~M_w6.9, Angkola ~M_w7.7, and Barumun ~M_w7.5.

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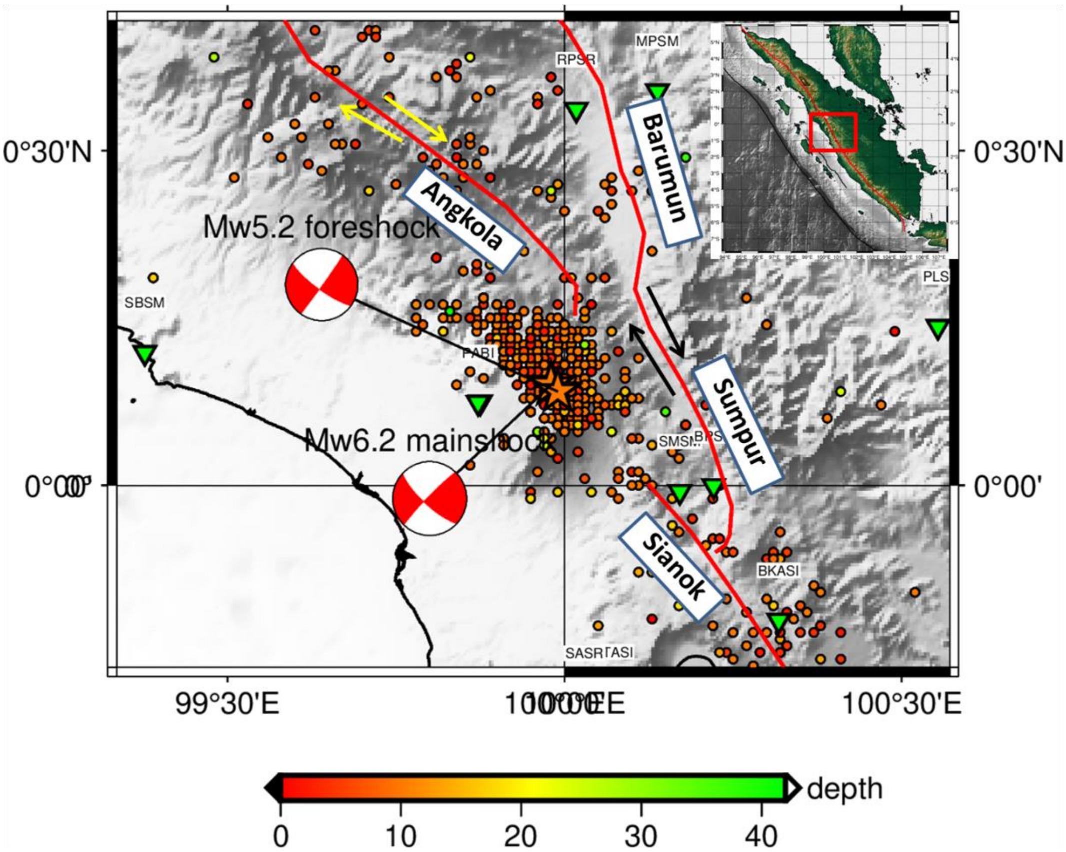


Figure 1. Epicenter map of Pasaman Barat earthquake Mw5.2 foreshock and Mw6.2 mainshock (BMKG) along with the focal mechanism for both earthquakes. The red circle is the distribution of aftershocks. The red lines are the active fault segments of Angkola, Barumun, Sumpur, and Sianok [17]. The green inverted triangle is the BMKG's seismic station network. The study area (red box) is shown on the inset map of Sumatera Island.

Based on the catalog of significant and destructive earthquakes from BMKG, 2018, The history of destructive earthquakes that have occurred in Pasaman Barat is the Talu earthquake, March 8, 1977, with a moment magnitude of M_w5.5 at a hypocenter depth of 22 Km. Felt VIII MMI in Sinurut and Talu which resulted in building damage and casualties. On February 25, 2022, at 01:39:29 WIB , there was a strong and destructive earthquake n Pasaman Barat and surrounding areas. This event was preceded by a preliminary earthquake with a magnitude of M5.2 at 01:35:10 UTC and coordinates of the epicenter are in 0.14^0N and 99.94^0E M_w6.1 with a hypocenter depth of 10 km and the focal mechanism is the strike-slip fault (figure 1). Based on information from INATEWS BMKG, this earthquake was felt on the intensity scale of VI-VII MMI (Modified Mercalli Intensity) in Talamau dan Kajai, V MMI in Pasaman Barat and Pasaman, III-IV MMI in Agam, Bukittinggi, Padang Panjang and II-III MMI in Kota Padang city, Padang Pariaman, Pariaman city. According to geologists and seismologists, the

Pasaman Barat earthquake was caused by an active fault in the Talamau and Kajai regions. The Pasaman Barat earthquake On February 25, 2022 caused damage to buildings including houses severely damaged 103 units, moderately damaged five units and lightly damaged 317 units and also caused casualties of around five people, injuring 60 people and evacuating 1000 people. Due to the amount of damage and casualties caused by the Pasaman Barat earthquake with a moment magnitude of Mw6.1, it is necessary to know how much the level of shock caused by the earthquake by estimating the peak ground acceleration (PGA) in the bedrock and peak surface acceleration. Peak ground acceleration (PGA) is one of the parameters that can explain the level of damage caused by the earthquake; then it can be classified as the damage potential of an earthquake based on the characteristics of soil and become a tool to justify structural damage [2], [4-7], [13]. The peak ground acceleration (PGA) value used to determine the damage to the building structure uses the reference from [22] shown in Table 1.

Table 1. PGA values that correlate with damage to building structures [22]

Potential damage	**none**	**None**	**None**	**Very light**	**Light**	**Moderate**	**Moderate Heavy**	**Heavy**	**Very heavy**
Peak Acc (%g)	<0.05	0.3	2.8	6.2	12	22	40	75	>139

According to [10], peak ground acceleration (PGA) caused by an earthquake is the implementation of inertial forces acting on the mass of the structure, which has a correlation to the effective earthquake force. Peak ground acceleration (PGA) is affected by the earthquake magnitude, focal mechanism, local site condition, geology and topographic condition [6], [11], [14]. Peak surface acceleration (PSA) is a very important parameter information for designing earthquake-resistant buildings [14]. Peak surface acceleration (PSA) is influenced by the soil type classification based on the shear wave velocity at 30 meters depth (Vs30) [19], [23], [24], [25]. This study, determining the estimation of peak ground acceleration using the GMPE (Ground Motion Prediction Equation) from Boore's (1997). The parameters used in Boore's (1997) GMPE attenuation are the moment magnitude(M_w), and the Joyner-Boore distance effect (R_{jb}) [2] , [12]. In addition, other parameters are used, such as the type of fault (reverse slip, strike-slip), the effect of ground conditions represented in the shear wave velocity at a depth of 30 meters (V_{s30}) and the reference shear wave velocity (V_A) [2],[12]. The GMPE equation is used in this study because it is specialized for determining peak ground acceleration (PGA) values at bedrock based on data from shallow crustal earthquakes with active reverse fault and strike-slip fault types, so it is considered suitable for determining peak ground acceleration (PGA) values in this study. The peak surface acceleration (PSA) value is determined from the amplification factor based on the classification of soil types and peak ground acceleration (PGA) at bedrock. This study aims to estimate the peak ground acceleration (PGA) in bedrock and peak surface acceleration (PSA) due to the Pasaman Barat earthquake with the magnitude $M_w 6.2$. The results obtained are expected to be used to mitigate and map which areas are vulnerable to future earthquake disasters in the Pasaman Barat area.

REGIONAL GEOLOGY

The regional geology of Pasaman Barat is included in the geology sheet of Lubuk Sikaping. Geological conditions in Pasaman Barat lithologically consist of sedimentary rocks, metasediments, young volcanic rock sand intrusive rocks and belong to the pre-tertiary rock group [16]. This group of pre-tertiary rocks is covered by tertiary sedimentary rocks, which consist of sandstone, quartz, shale, siltstone, and clay-stone (shapes formation), while volcanic rocks, which are the product so fold Talu, Pasaman, and Aligoro volcanoes which form young volcanic rocks are indistinguishable [16]. Quaternary volcanic rocks are the result of the activities of the old Pasaman volcanoes, Mount Gajah and Mount Talamau.

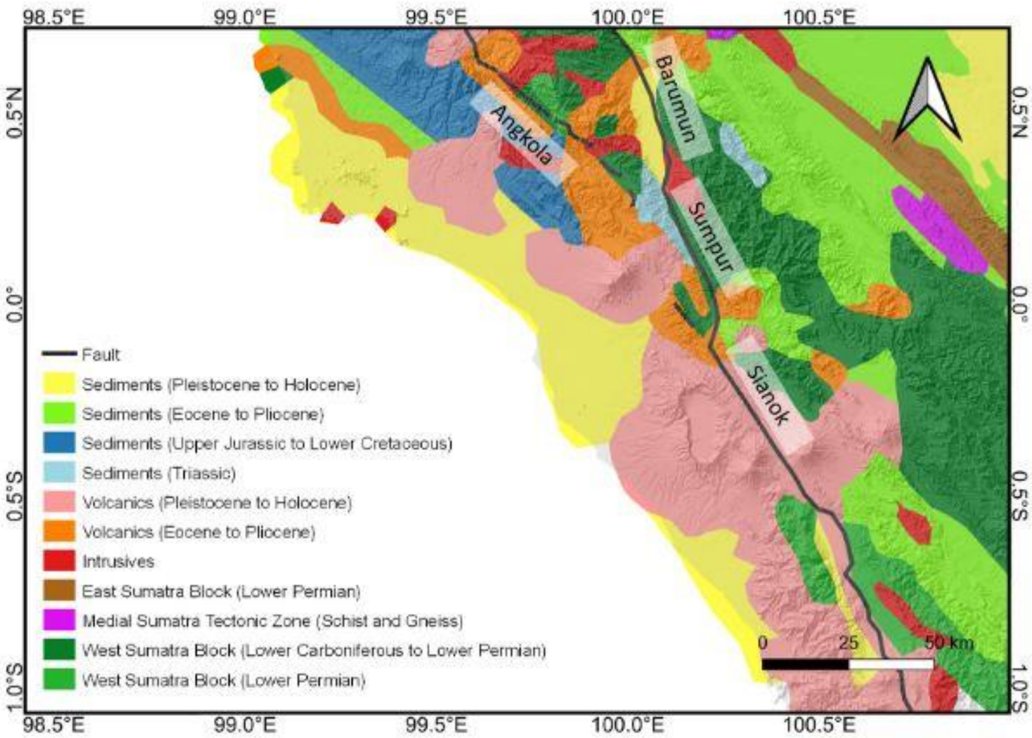


Figure 3. The regional geology of Pasaman Barat is included in the geology sheet of Lubuk Sikaping [3], [16]

The results of the activities of the old Pasaman volcano consist of andesitic-basaltic lava, volcanic lava, and volcanic classics, while the product of Gunung Gajah is andesitic and vesicular dacite lava and porphyritic andesite-basalt [3], [8]. The youngestvolcanic deposits originating from the Talamau volcano are found in the formofacid-base lava, tuff sandstone and silt [16].

DATA AND METHOD

Data

The data used in this study are the main earthquake information parameters such as magnitude, epicenter coordinates, depth of the earthquake and the shear wave velocity model data at a depth of 30 meters (V_s30). Shear wave velocity data at a depth of 30 meters (V_s30) in Pasaman Barat obtained from Global V_s30 model USGS (United States Of Geology Survey).

Method

Methods used to estimate peak ground acceleration (PGA) at bedrock in this study use Boore's (1997) GMPE attenuation. The attenuation equation is as follows :

$$\log Y = b_1 + b_2(M-6) + b_3(M-6)^2 + b_4 r + b_5 \log r + b_v(\log Vs_{30} - logV_A) \quad (1)$$

where Y is peak ground acceleration at bedrock (g), M is magnitude, $r = \sqrt{d^2 + h^2}$, d is epicenter distance (km), h is hypocenter depth (km), V_A is reference shear wave velocity

(m/s) and b_1, b_2, b_3, b_4, b_5 and b_v constant. Meanwhile, to determine the peak surface acceleration using the equation :

$$PSA = F_{PGA} \; . \; PGA_{bedrock} \tag{2}$$

Where PSA is peak surface acceleration (g), F_{pga} is the Amplification factor parameter, which is influenced by the type of soil classification (table 2) and $PGA_{bedrock}$ is peak ground acceleration (g).

Table 2. Parameters of the amplification factor for the period T = 0 seconds (SNI 1726 - 2012) [9]

Classification of Soil	Parameters of the Earthquake Acceleration on the Surface (PSA) for the Period T = 0				
	PGA ≤ 0,1	PGA = 0,2	PGA = 0,3	PGA = 0,4	PGA ≥ 0,5
Rock	0.8	0.8	0.8	0.8	0.8
Soft Rock	1.0	1.0	1.0	1.0	1.0
Hard soil	1.2	1.2	1.1	1..0	1.0
Medium Soil	1.6	1.4	1.2	1.1	1.0
Soft Soil	2.5	1.7	1.2	0.9	0.9

The Vs30 data parameter is used as input to the peak ground acceleration attenuation model equation, in addition to estimating the soil type classification (siteclass) and also to obtain the amplification factor parameter based on [9]. Then, in this study, grid points were made in the Pasaman Barat with a total of 253 research grid points and a distance between grid points of 2 km where one grid point contains a value of peak ground acceleration and peak surface acceleration (Figure 4).

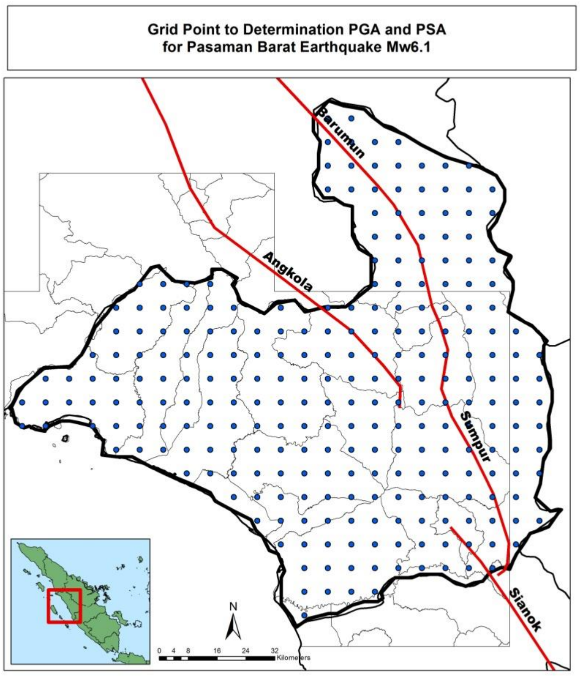


Figure 4. The map of the research grid points to the Pasaman Barat; the red line is the active faults of Sianok, Angkola, Sumpur, and Barumun[17]. The study area (red box) is shown on the inset map of Sumatera Island.

Mapping the estimated peak ground acceleration at bedrock ($PGA_{bedrock}$) and peak surface acceleration (PSA) using arcgis 10 software using the interpolation method. The flowchart in this research is shown in Figure 5.

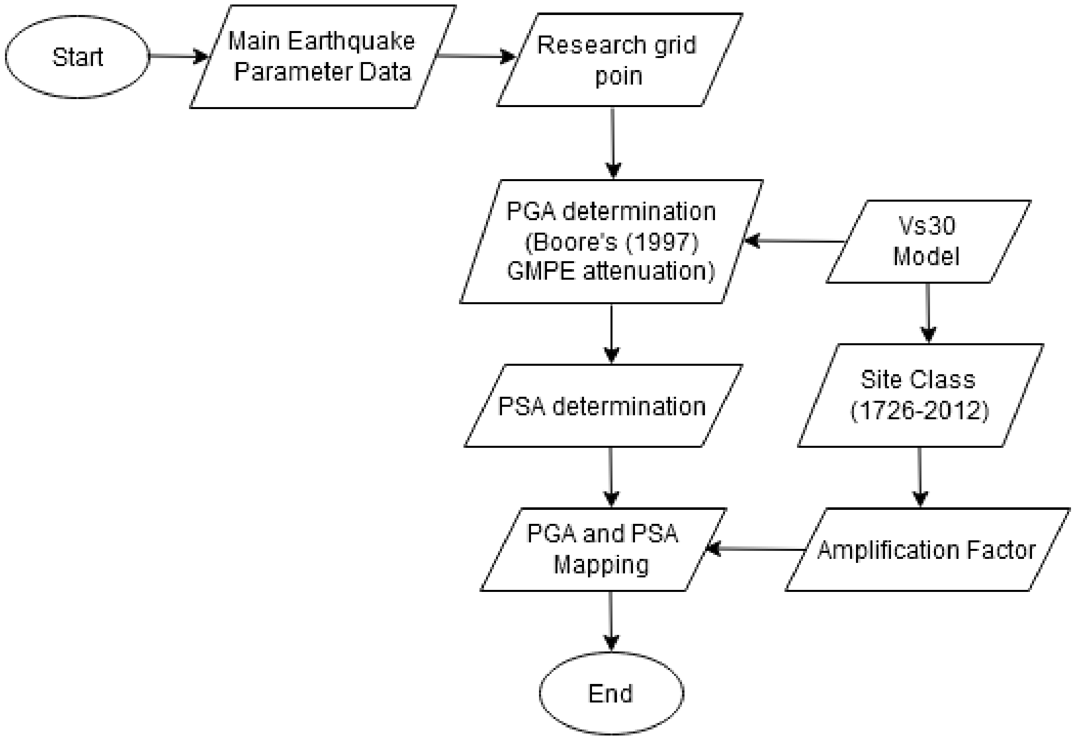


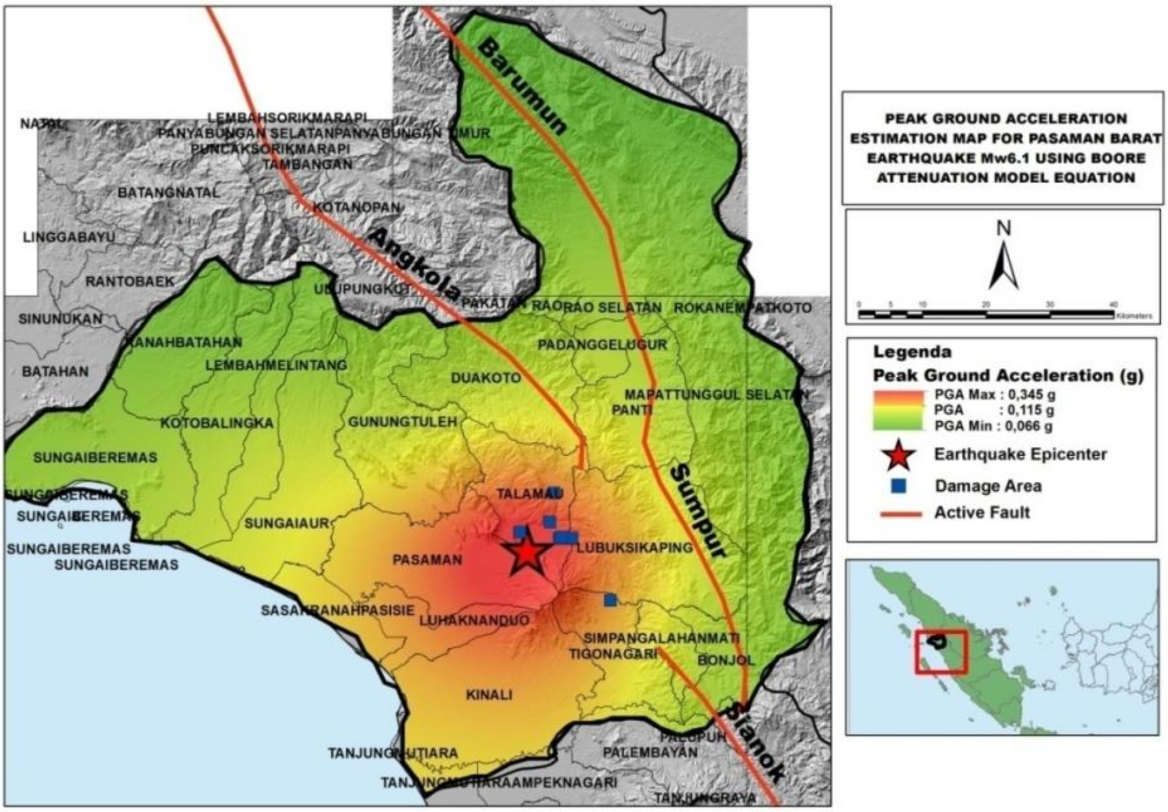
Figure 5. flowchart in this research

RESULTS AND DISCUSSION

PEAK GROUND ACCELERATION AT BEDROCK ($PGA_{bedrock}$)

The results of the analysis and mapping of the peak ground acceleration at bedrock ($PGA_{bedrock}$) estimation using the Boore attenuation model equation (1997) due to the Pasaman Barat earthquake, February 25, 2022, with M_w6.1 are shown in Figure 6. In Figure 6 it can be seen that the peak ground acceleration at bedrock ($PGA_{bedrock}$) values due to the Pasaman Barat earthquake with M_w6.1 ranged from 0.066 g to 0.345 g, while relatively high peak ground acceleration at bedrock ($PGA_{bedrock}$) values were obtained around 0.115 g to 0.345 g and occurred in the Pasaman, Talamau, Luhak Nan Duo, Kinali areas, Tigonagari and Lubuk Sikaping. Then relatively low peak ground acceleration at bedrock ($PGA_{bedrock}$) values ranging from 0.066 g to 0.084 g occur in the Sungai Baremas, Tanah Batahan, and Koto Balingka. Meanwhile, for areas that experienced a lot of damage to buildings, it occurred in Kajai, Tigonagari, Malampah, Rimbo Panti with peak ground acceleration at bedrock ($PGA_{bedrock}$) values ranging from 0.264 g to 0.345 g. The level of damage to buildings caused by the Pasaman Barat earthquake was thought to be caused by strong ground shaking, and the distance was very close to the location of the earthquake epicenter. High peak ground acceleration at bedrock ($PGA_{bedrock}$) values are associated with close-range earthquakes where rock vibrates with high-frequency content and high peak ground acceleration ($PGA_{bedrock}$) values can reach inelastic ground response so that the material attenuation becomes relatively high [2], [13], [15]. According to [18], the peak ground acceleration value due to a close-range earthquake is influenced by the focal mechanism earthquake, the direction of the fault propagation (rupture direction), and the possibility of permanent displacement. The farther from the epicenter peak ground acceleration value is relatively low, this happens because the earthquake energy has propagated a long distance, so there is sufficient time for the soil media to absorb some of the earthquake energy [15], [21].

Figure 6. Map of the peak ground acceleration at bedrock ($PGA_{bedrock}$)with period $T = 0$ s, using Boore's (1997)



GMPE attenuation at the Pasaman Barat earthquake on February, 25, 2022 $M_w 6,1$. Red lines are the active faults of Sianok, Angkola, Sumpur, and Barumun [17]. The study area (red box) is shown on the Sumatera Island inset map.

The high peak ground acceleration caused by the earthquake is influenced, among other things, by the source of the earthquake, the propagation of the earthquake waves and also the local soil conditions (local site effect) [13], [15]. Local site effect or local soil conditions are determined from the value of the average shear wave velocity with a depth of 30 meters ($V_s 30$) use of the $V_s 30$ value to identify building damage based on the type of soil classification. In this study, the $V_s 30$ value in the Pasaman Barat was obtained from the USGS $V_s 30$ slope model and its distribution is shown in Figure 7. In Figure 7, the type of soil classification based on the parameter value $V_s 30$ in the Pasaman Barat region is dominated by moderate soil to rock. Areas that have moderate soil types are located on the coast and somehilly valleys, while rock sites are located in hilly and mountainous areas. Areas that experienced severe damage are marked with a blue box, such as Kajai, Malampah, Tigo Nagari, Talamau and Rimbo Panti which have a $V_s 30$ value of around 180 m/s to 350 m/s with a classification type moderate soil, so that the area is experiencing high amplification and peak ground acceleration.

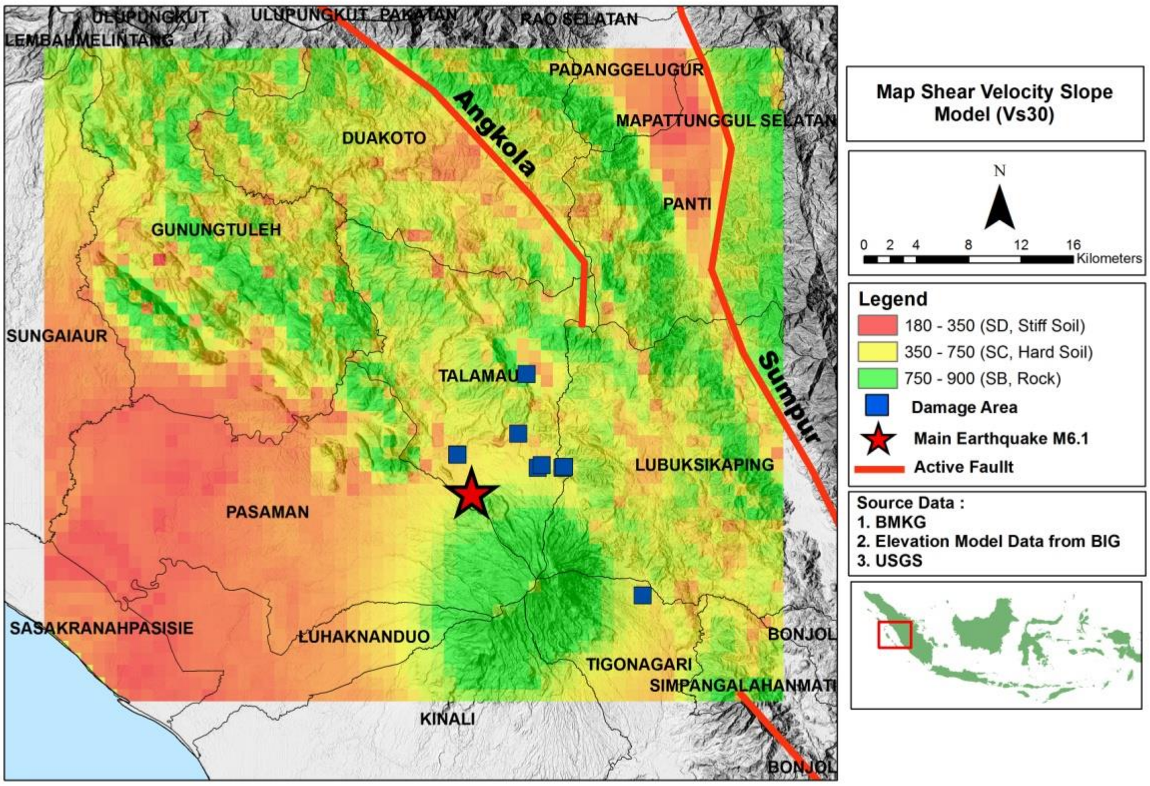


Figure 7. Map of model distribution of shear wave velocity at a depth of 30 meters (V_s30) in the Pasaman Barat from USGS (United States of Geology Survey). Red lines are the active faults of Sianok, Angkola, Sumpur, and Barumun [17]. The study area (red box) is shown on the Sumatera Island inset map.

In Figure 7, a relatively high V_s30 values in the Pasaman Barat area ranging from 350 m/s to 750 m/s and 750 m/s to 900 m/s which are marked in yellow and green on the map of Figure 6, appear to be influenced by topographical conditions in the form of hills which are dominated by hard soil and rock resulting in a low amplification process and the ground motion are quite weak.

Peak Surface Acceleration (PSA)

In this study, the peak surface acceleration due to the Pasaman Barat earthquake, on February, 25, 2022, $M_w6.1$ was analyzed based on the amplification factor (SNI 1726 - 2012)[7], which is influenced by the type of soil classification from parameter Vs30 and the peak ground acceleration value in bedrock base. The results analysis of the peak surface acceleration are shown in Figure 8. In Figure 8, the results of the distribution of peak surface acceleration due to the Pasaman Barat earthquake ranged from 0.223 g to 0.627 g relatively high peak surface acceleration values were obtained around 0.455 g to 0.627 g and occurred in areas that experienced heavy damage, such as Pasaman, Talamau, Tigo Nagari, Kajai, Rimbo Panti, and Malampah, while the results for low peak surface acceleration values range from 0.223 g to 0.334 g and occur in the area of Padang Gelugur, Batahan, Koto Balingka, tuleh mountain, Dua Koto, Bonjol, Rao and South Rao. Areas with relatively high peak surface acceleration occur due to the process of amplification of seismic waves which is affected by the low shear wave velocity of 30 meters (V_s30) depth and the type of soil classification (site class) is dominated by stiff soil.

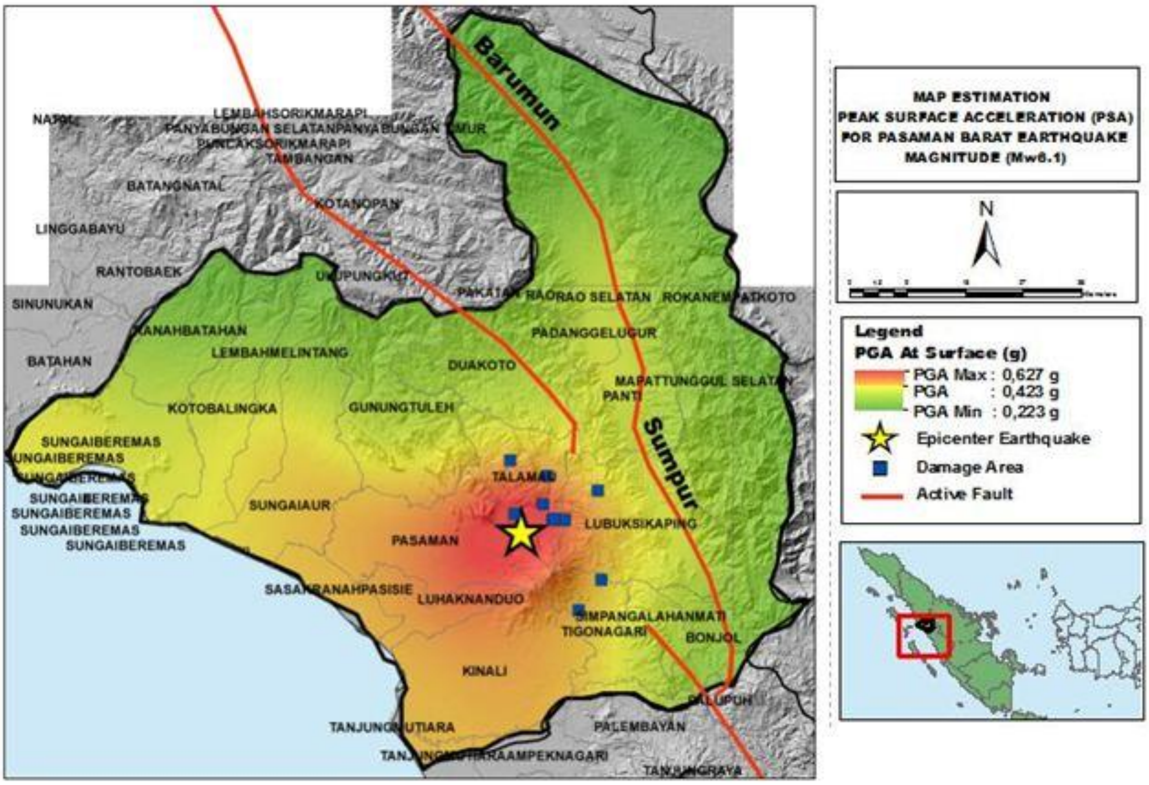


Figure 8. Map of peak surface acceleration (PSA) due to the Pasaman Barat earthquake, on February, 25 2022, with a M_w6.1. Red lines are active fault of Sianok, Angkola, Sumpur and Barumun [17]. The study area (red box) is shown on in the inset map of Sumatera Island.

In Figure 8, it can also be seen that the ground acceleration value on the surface is highly correlated with the value of the shear wave velocity at a depth of 30 meters ($\mathbf{V_s}$30) (Figure 7). The process of strengthening the amplification factor of the earthquake on the ground acceleration on the surface is strongly influenced by the thickness of the sediment layer, the thicker the sediment layer, the higher the peak ground acceleration value and also influenced by the attenuation function factor on the distance to the earthquake epicenter. The amplification value factor is greater on soft soil where the shear wave velocity or vs. is smaller[18], [19]. [20], there for the soil type characteristic factors, amplification factors and local site conditions contribute greatly to building damage. [3] in their research on the Existence of the Talamau Segment Fault Based on Teleseismic Data and Satellite Gravity results show that the damage area caused by the West Pasaman earthquake is in the high asperities zone, this is in line with the results of this study with high PGA values in bedrock and on the surface in the asperities zone. In addition, the West Pasaman earthquake is a type of shallow crustal earthquake that has produced single asperities that can cause high surface shaking.

CONCLUSION

The peak ground acceleration at bedrock ($\mathrm{PGA}_{bedrock}$) and peak surface acceleration (PSA) due to the Pasaman Barat earthquake, on February 25, 2022, with M_w6.1 ranged from 0.066 g to 0.345 g and 0.223 g to 0.627 g. Peak ground acceleration (PGA) at bedrock and peak surface acceleration (PSA) values on the surface in the damage area ranged from 0.264 g to 0.345 g and 0.223 g to 0.334 g. Areas of damage occurred in Kajai, Rimbo Panti, Malampah and Tigo Nagari. Building damage caused by the West Pasaman earthquake is thought to have been caused by strong ground shaking and was also influenced by the source of the earthquake, the propagation of earthquake waves and also local soil conditions (local site effect).

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