Earthquake hazard model with AVS30 in Sukabumi, West Java Province

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Abstract. The potential surface shocks due to the earthquake in Sukabumi is quite high. The purpose of this study is to provide an overview of the potential distribution of earthquake hazards on the earth’s surface. The methodology used for the potential earthquake hazard is the Peak Ground Acceleration (PGA) approach which is corrected by AVS30 analysis. The final results of the study can provide an overview of the potential of earthquake surface shocks grouped into three categories, namely low, medium, and high hazards. The variables used in this study were four types, namely: subsurface earthquake potential, slope shape, slope texture, and slope gradient. The study results of the potential for earthquake shocks can provide information on the potential hazards of earthquakes on the largest land surface in the Sukabumi City area and around the Cimandiri fault.

1. Introduction

Indonesia is a disaster-prone country [1]. Aside from being rich in natural resources, Indonesia also vulnerable to natural disasters including earthquakes. Indonesia’s geological conditions are very complex and can be a trigger for disasters [1]. This condition is also supported by data of disaster incident collected by National Disaster Management Agency (BNPB) in the Indonesian Disaster Data and Information (DIBI) portal. In DIBI, the number of disasters occurring during in 12 years (2005-2017) recorded 19,928 incidents or an average of about 4 incidents per day, which were dominated by hydrometeorological disasters (floods, landslides, extreme waves, land and forests fires, drought, and extreme weather) with a total of 19,076 events (95.72%), while for geological disasters (earthquakes, tsunamis and volcanic eruptions), there have been 852 incidents (4.28%).

Judging from the impact, geological disasters, especially earthquakes, are the most detrimental types. This condition is in line with the results of the recapitulation of the disaster impact which was published by the Centre for Research on the Epidemiology of Disasters (CRED) for the period 1900 to October 2018 which shows that the greatest direct loss due to disasters is caused by earthquakes. The total loss due to the earthquake reached 13.3 Billion Dollars or around 200 Trillion IDR or around 43% of the total loss due to all major disasters in Indonesia. Recapitulation of victims due to the earthquake showed 201,871 victims died or around 82% of the total deaths due to major disasters in Indonesia [2]. Thus, even though there are relatively fewer incidents of the other types of disasters, earthquakes disasters are the ones with the greatest impact. From potential aspects or disaster risks, earthquakes are also a type disaster that has a big potential impact.
Earthquake disaster risk when viewed from the results of a study conducted by BNPB in 2015, a total of 193 regencies and cities in Indonesia are categorized as the most dangerous areas (processed from DIBI portal). When viewed from the order of the population in the most earthquake-prone areas in the certain regencies and cities are Bandung Regency, Bandung City, Sukabumi Regency, and Cianjur Regency. Meanwhile, when viewed from a potentially hazardous area, Sukabumi Regency is the widest area for medium and high hazard areas with total area of hazardous area reaching 262,949 hectares, and when viewed from the history of earthquake disaster occurrence in this region, there have been at least 9 incidents with number of affected people (injured, dead, and evacuated) as many as 1,047 at the end of 2018 (processed from DIBI portal). By considering the potential of the current earthquake disaster, the author tries to make an approach of the potential for surface shocks due to earthquakes in the Regency and City of Sukabumi.

2. Theoretical Review

Tectonic earthquakes are dynamic natural phenomena caused by shifting rock masses in active tectonic zones. The rock shift is caused by tensional and compressional forces that continue to occur in the lithology layer below the surface. When the energy exceeds the resistance of rock mass, deformation occurs and causes earthquake energy release. The intensity and frequency of earthquake incidents also depend on whether or not the deformation process is active and the level of elasticity of the rock [3]. According to Indonesian Dictionary, earthquake is a natural incident in the form of vibrations or wavy movements on the skin of the earth caused by the origin of energy. While the term shock can be interpreted as a strong shake which in this case is caused by an earthquake. The secondary impacts of earthquakes that can occur include landslides, rock debris, and rock flows, as well as the impact of damage to death as a result of seismic shaking, landslide, and land settlement [4].

In the report published by Japan’s Earthquake Research Committee in 2015, explained that one approach to identify earthquake hazards was through mapping the shock intensity on the surface by multiplying the soil amplification factor and the intensity of shocks on the bedrock. Bedrock is a subsurface layer that can support building structures in the form of relatively uniform solid rock layers [5]. One of the parameters needed to determine the soil amplification factor is the average shear wave velocity distribution from the ground level to the depth of 30 m (Vs30 or AVS30). Ideally, the measurement of shear wave velocity is carried out directly in the field (borehole technique), but requires large funding and a long time, so it is considered ineffective or not economical. An alternative way to produce ground amplification factor is the empirical method approach which uses the following equation [10]:

\[
\text{Log}(G) = 1.35 - 0.47\text{LogAVS30} \pm 0.18
\]

where, G is the ground amplification factor for PGA (peak acceleration).

Topographic classification concluded that there are morphological forming factors that can be associated with the potential magnitude of surface shocks due to earthquakes [6,7]. Furthermore, the character and process of formation of surface soils in Indonesia have similarities with Japan, so that using the AVS30 classification (averaged velocity of S-wave shallower than 30 m) which is based on topographic characteristics of soil amplification factors in Japan, the estimation of soil amplification factor in Indonesia can be calculated [6].

The intensity of shocks on the surface is obtained from the results of analysis of shock intensity data on bedrock and Ground Amplification Factor [6]. The shock intensity data on bedrock can be seen from the derivatives of the Indonesian Earthquake Hazard Map (SNI 1726: 2012). While the ground amplification factor data were obtained from the calculation of AVS30 estimated based on the topographic class approach using DEM (Digital Elevation Model) raster data which was analysed by the conversion table published by NIED (National Research Institute of Earth Science and Disaster
Prevention) in 1994 [6]. The analysis of the intensity of shocks in bedrock in SNI 1726: 2012 is the result of probabilistic and deterministic seismic hazard analysis that based on the standards of the American Society of Civil Engineers/Structural Engineering Institute (ASCE/SEI) 7-2010 (2010) and FEMAP 750 [8]. The analysis has considered the historical and earthquake characteristics in the active fault region which is then calculated to describe the earthquake acceleration spectral response parameters in the bedrock [8].

3. Research Method

This research was conducted using a quantitative approach to secondary data. To obtain the final results, this study begins with data collection and processing to obtain a Surface Shock Map with a scale of 1:50,000. To obtain a surface shock map, several research variables were used. These variables are geological conditions, bedrock acceleration, and topography. Each of these variables has an indicator. For the geological conditions variable, the indicator used is the distribution of geological faults. For the bedrock acceleration variable, the indicator used is the value of the shock intensity in the bedrock. While the topographic variables, the constituent indicators are texture, gradient, and shape of the slope. According to the stages carried out by the Earthquake Research Committee in Japan (2015), in general the process of making earthquake hazard maps begins with mapping the shock intensity (peak acceleration) on bedrock using earthquake scenario analysis or probabilistic approaches and attenuation distance relationships. The next step is mapping the shock intensity on the surface by multiplying the soil amplification factor and the intensity of shocks on the bedrock.

The stage of this research is carried out by processing seismic data by performing topographic analysis of DEM data [7]. The three characteristics analysed related to topography are slope gradient, slope texture, and slope shape. Topographic characteristics were then analysed to produce 24 topographic classes of data by observing the slope gradient, slope texture, and slope shape [7]. The making of topographic classes uses semi-automatic techniques. The division/classification of the 24 classes produced is then used as input data to produce AVS30 data based [7, 9]. The next process is to convert the value of AVS30 to the value of the Amplification Factor using the equation [7]

\[ \log(G) = 1.35 - 0.47 \log \text{AVS30} \pm 0.18 \quad (1) \]

where G is the ground amplification factor for peak acceleration-PGA. Next, data processing of shock intensity on the surface is carried out based on the results of multiplication between the amplification factor values and the shock intensity (peak acceleration) values in the bedrock. The PGA/Peak Ground Acceleration value in the bedrock used is for the probability of exceeding 10% in 50 years [10]. In conducting slope gradient analysis, the classification with calculation techniques used through grid analysis with formula [6]:

\[ \text{slope degree} = \arctan \left( \sqrt{\left( \frac{dz}{dx} \right)^2 + \left( \frac{dz}{dy} \right)^2} \right) \times 180/\pi \quad (2) \]

where:

\[ \frac{dz}{dx} = \frac{(c+2f+i)-(a+2d+g)}{8 \times \text{cellsize}} \quad (3) \]
Further, to analyse slope texture, the correction factor of DEM data is used by counting the median value of each cell. Illustration of analysis that has been done is presented in Figure 1.

\[
\frac{\partial z}{\partial y} = \frac{(g + 2h + i) - (a + b + c)}{8 \cdot y \cdot \text{cellsize}}
\]

(4)

Figure 1. Illustration of slope texture analysis [6]

In slope shape analysis, a Laplacian filter used to classify a cell’s convexity to raster analysis [6]. The analysis of slope shape that has been used can be seen in figure 2.

Figure 2. Illustration of slope shape analysis [6]

Topographic characteristics were then analysed by making topographic classes aimed at producing 24 topographic classes of data by observing the slope gradient, slope texture, and slope shape. The making of topographic classes using semi-automatic techniques using DEM data [7]. The division/classification of the 24 classes produced is then used as input data to produce AVS30 [9]. Topographic class and AVS30 conversion tables are presented in Table 1.

The next process is to convert the value of AVS30 to the value of the Ground Amplification Factor using the equation \( Log(G) = 1.35 - 0.47 \log \text{AVS30} \pm 0.18 \), where G is the ground amplification factor for peak acceleration-PGA [10]. Next, data processing of shock intensity on the surface is carried out based on the results of multiplication between the amplification factor values and the shock intensity (peak acceleration) values in the bedrock. The PGA/Peak Ground Acceleration value in the bedrock used is for the probability of exceeding 10% in 50 years obtained from the Indonesian 2012 Earthquake Source and Hazard Map [10]. The last step in processing surface shock data is to make earthquake hazard index data based on the value of the shock intensity on the surface. The hazard assessment is conducted to obtain conclusions from the results of the hazard index analysis (H) in the form of a hazard class. Hazard classes are classified based on the classification of hazard index values as follows: Low: \( H \leq 0.333 \), Medium: \( 0.333 < H \leq 0.666 \), High: \( H > 0.666 \) according to the classification of SNI 8182: 2017.

The model of surface shocks is made using a methodological approach using the geomorphological aspect assumptions in the form of the shape of the earth depicted in the Digital Elevation Model-DEM [10]. This data is then classified with topography classification and subsequently converted into topographic classes categorized in the AVS30 classification [10]. The AVS30 classification results,
calculated to get the Ground Amplification Factor value combined with the PGA value from the map of the shock intensity at the bedrock, and will produce a surface shock intensity value.

### Table 1. The Topographic Class Conversion Table to become the value of AVS30

| Topographic Class | AVS30 (m/s) | Topographic Class | AVS30 (m/s) | Topographic Class | AVS30 (m/s) |
|-------------------|------------|-------------------|------------|-------------------|------------|
| 1                 | 875        | 9                 | 260        | 17                | 217        |
| 2                 | 568        | 10                | 417        | 18                | 297        |
| 3                 | 898        | 11                | 190        | 19                | 239        |
| 4                 | 462        | 12                | 362        | 20                | 197        |
| 5                 | 406        | 13                | 165        | 21                | 239        |
| 6                 | 413        | 14                | 259        | 22                | 169        |
| 7                 | 608        | 15                | 213        | 23                | 173        |
| 8                 | 239        | 16                | 206        | 24                | 178        |

Source: [9]

### 4. Research Results

Sukabumi area has a high potential for subsurface shock (Peak Ground Acceleration), it can be seen from the results of the study contained in the 2012 Indonesian Earthquake Source and Hazard Map by Kementerian PU (2012). The value of PGA/Peak Ground Acceleration in the bedrock used in this study is for the probability of exceeding 10% in 50 years. The probability value is a potential seismic condition that is in accordance with conditions in Indonesia [10]. For the sukabumi region, most of the PGA values are 0.3 g (1 g = 9.81 m/s²) with a maximum value of 0.5 g spread in the central part of the study area. The topographic variable used in the study was built by looking at the three forming parameters. The parameters are slope gradient, slope texture, and slope shape. The condition of Sukabumi can be grouped based on the parameters that form the topographic variables to construct model of earthquake surface shocks [6]. After obtaining processed results which are the parameters of slope gradient, slope texture, and slope shape, then the slope class grouping process is then carried out as many as 24 classes [6]. This grouping process is carried out using the ArcGIS device with Raster Calculator tools. Based on the results of the analysis, the Sukabumi region has only 12 Classes from 24 Class Classifications [9].

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Figure 3. Map of the Earthquake Hazard Potential Index through the AVS30

5. Discussion
Based on the results of data processing that has been done, the effect of topographic parameters provides a model of surface shocks by correcting the Peak Ground Acceleration (PGA) value and classifying it into three index levels. In the final process of making an earthquake hazard model, the calculation results obtained with an area that has a high hazard index value in Sukabumi is 67,677.93 hectares with a
medium index value of 113,758.47 hectares. When viewed from the distribution of each District, the areas that has a High earthquake hazard index value is in the Districts of Jampang Tengah, Nyalindung, Cikembar, Warung Kiara, Geger Bitung, Bantargadung, Purabaya, Gunungguruh, Palabuhanratu, Cincantayan, Simpenan, Lengkong, Cireunghas, Kebonpedes, and Lembursitu with the total area of over 1,000 hectares. As for Low index value, a lot of them are in Districts of Ciemas, Tegal Buleud, Cisolok, Kabandungan, and Cikidang with an area of over 10,000 hectares each. The modelling of potential surface shocks due to earthquakes is carried out using the AVS30 approach. This approach is an estimate of the S-wave velocity at a distance of 30 m below ground level [6].

Based on the results of data processing that has been done, the effect of topographic parameters provides a model of surface shocks by correcting the Peak Ground Acceleration (PGA) value and classifying it into three index levels. In the final process of making an earthquake hazard model, the calculation results obtained with an area that has a high hazard index value in Sukabumi is 67,677.93 hectares. The distribution of high earthquake hazard index value is in the District of Jampang Tengah, Nyalindung, Cikembar, Warung Kiara, Geger Bitung, Bantargadung, Purabaya, Gunungguruh, Palabuhanratu, Cincantayan, Simpenan, Lengkong, Cireunghas, Kebonpedes, and Lembursitu with the total area of over 1,000 hectares. As for Low index value, a lot of them are in Districts of Ciemas, Tegal Buleud, Cisolok, Kabandungan, and Cikidang with an area of over 10,000 hectares each. Completely, the final results of earthquake hazard index modelling can be seen in Figure 3 and the total number of the hazard index in each level and in each District can be seen in Table 2.

Table 2. Table of Area with earthquake hazard index values for each District in Sukabumi in hectares

| No | District       | Area at Hazard level (Ha) | No | District       | Area at Hazard level (Ha) |
|----|----------------|--------------------------|----|----------------|--------------------------|
|    | Low           | Medium                   | High| Low           | Medium                   | High|
| 1  | Ciemas        | 22.878                   | 5.546| 890 | 29 Sukabumi    | 1.367                   | 1.435| 199 |
| 2  | Ciracap       | 7.863                    | 6.718| 474 | 30 Kadudampit  | 5.506                   | 1.432| 17  |
| 3  | Walurun       | 7.659                    | 2.415| 51  | 31 Cisaat      | 82                      | 1.246| 999 |
| 4  | Surade         | 6.129                    | 5.380| 476 | 32 Gunungguruh | -                      | 330 | 2.314 |
| 5  | Cibitung      | 6.255                    | 1.996| 241 | 33 Cibadak     | 2.513                   | 3.420| 413 |
| 6  | Jampang Kulon | 5.034                    | 1.748| 185 | 34 Cicantayan  | 262                     | 1.443| 1.809|
| 7  | Cimanggu      | 4.461                    | 1.024| 39  | 35 Caringin    | 2.265                   | 1.325| 160 |
| 8  | Kali Bunder   | 7.907                    | 926  | 50  | 36 Nagrak     | 5.172                   | 1.685| 30  |
| 9  | Tegal Buleud  | 21.604                   | 3.128| 720 | 37 Ciambar     | 4.671                   | 968  | 9   |
| 10 | Cidolog       | 9.116                    | 1.015| 50  | 38 Cicurug     | 3.687                   | 1.546| 25  |
| 11 | Sagaranten    | 8.443                    | 2.305| 115 | 39 Cidahu      | 2.492                   | 976  | 17  |
| 12 | Cidadap       | 7.142                    | 1.088| 32  | 40 Parakan Salak | 3.025                  | 665  | 14  |
| 13 | Curugkembar   | 4.505                    | 1.074| 31  | 41 Parung Kuda | 1.354                   | 1.124| 38  |
| 14 | Pabuanan      | 9.283                    | 2.137| 119 | 42 Bojong Genteng | 1.255                | 618  | 15  |
| 15 | Lengkong      | 4.831                    | 7.945| 1.546| 43 Kalapa Nunggal | 4.257               | 775  | 11  |
| 16 | Palabuhanratu | 2.501                    | 4.386| 2.305| 44 Cikidang    | 10.943                  | 4.405| 179 |
| 17 | Simpenan      | 7.012                    | 8.552| 1.744| 45 Cisolok     | 16.182                  | 992  | 36  |
| 18 | Warung Kiara  | 212                      | 3.353| 5.921| 46 Cikakak    | 9.768                   | 1.650| 77  |
| 19 | Bantargadung  | 275                      | 3.275| 4.092| 47 Kabandungan | 13.070                 | 659  | 10  |
| 20 | Jampang Tengah| 1.683                    | 7.493| 9.591| 48 Baros       | -                      | -    | 552 |
| 21 | Purabaya      | 4.068                    | 5.677| 3.708| 49 Lembursitu  | -                      | 31   | 1.074|
| 22 | Cikembar      | 6                        | 847  | 7.367| 50 Cibeureum   | -                      | 20   | 902 |
| 23 | Nyalindung    | 28                       | 1.405| 8.735| 51 Citamiang   | -                      | 1    | 399 |
8

6. Conclusion
Based on the results of the study related to the condition of the Sukabumi region, which is an area that has the potential for earthquake shocks. Areas that have the potential for surface shocks due to high earthquakes are scattered around the central part of Sukabumi District and Sukabumi City. The AVS30 methodology approach for correcting earthquake hazard potential distribution based on Peak Ground Acceleration (PGA) data can be done on a better scale. To get better research results, it is necessary to do an analysis using a renewed PGA map for a larger scale.

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