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Seismic Hazard Microzonation of Tasikmalaya City, West Java Province, Indonesia

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Abstract: Tasikmalaya, as the capital city of Tasikmalaya Prefecture in West Java Province, Indonesia, which has a high density population. More than 600.000 peoples are living in this city, many buildings, and some important infrastructures has been built. Base on probabilistic seismic hazard map of Indonesia by National Standardization Agency, shown the Tasikmalaya City located at the region of Peak Ground Acceleration (PGA)= 0.4 – 0.5 g and Pseudo Spectral Acceleration (PSA S_S: 0.2 second and PSA S_1: 1 second= 0.7 – 0.8g and 0.4 – 0.5g, for Soil Class SB, 2% probability in 50 years. In order to mitigate seismic risk, a potential seismic hazard micro-zonation map has been produced as guidance for urban city planning. We classify three potential seismic hazard micro-zonation based on the wave velocity of Vs30. The first class is High Potential Seismic Hazard Zones (Vs30 < 175 m/second and amplification 2), the second is Medium Potential Seismic Hazard Zonation (Vs30= 175 – 350 m/second and amplification 1.5), and the third is Low Potential Seismic Hazard Zonation (Vs30 = 350 – 750 m/second and amplification 1). The assessment of potential seismic hazard and risk refer to National Standardization Agency, the building and non-building has the risk categories I, II, III, and IV which are located in High, Medium and Low Potential Seismic Hazard Zonation's. The risk category recommend to have building and non-building structures with seismic design categories D. However, the building and non-building that have been built do not follow the seismic design particularly design category D. Therefore, potential seismic risk and seismic design categories are recommended to be applied to spatial planning as an effort to mitigate earthquake risk in the city of Tasikmalaya. We defined 9 active faults and 5 potential active faults surrounding in the city. Most of them are threaten the settlement with a variety of maximum credible earthquake.

Keywords: Seismic Micro-zonation, Risk, Seismic Design Category, Tasikmalaya-Indonesia

1. Introduction

Tasikmalaya City is located in intermountain basin and is surrounded by young volcanoes Galunggung – Talagabodas (west) and the oldest volcanoes of Sawal (north) and Cibeureum (south This city covers an area of 183.85 km² and has a population of 662.723 peoples [22]. This region and surrounding area has two main earthquake sources are the earthquakes originating from the subduction zone between the Indian-Australian Ocean Plate and the Europa-Asian/Eurasia Continental Plate in the south and beneath of West Java and the earthquake originating from the upper crustal of active faults at the mainland of West Java (Figures 1 and 2). Earthquake disasters from these two earthquake sources can threaten the City of Tasikmalaya at any time. In order to mitigate and protect this city from seismic risk, a mapping and investigation of geology, geomorphology, seismotectonic and seismic hazard microzonation has been done to assess the potential seismic hazard. The result of mappings and investigations consist of three basic maps are geological, seismotectonic, and microzonation maps of Tasikmalaya City and surrounding areas on a scale of 1: 50.000. The geological maps of Tasikmalaya City and surrounding areas as the basic map of seismotectonic map which are show the types of rocks, structure geology distribution and the dimensions of active faults and potential active faults. On the other hand, the microtremor microzonation map as the result of mapping and investigation shows the distribution of Vs30 and site class.

The aim of the objective of this effort consists of four main parts: 1st to establish the potential seismic hazard map of Tasikmalaya City, 2nd implement the data and information of potential seismic hazards to mitigate the seismic risk, 3rd create the city spatial planning, and 4th make the regulation for city development programs.

2. Geology, Active and Potential Active Faults

The geology of this region consist of geomorfology, lithology and structure geology. Geomorphology of Tasikmalaya City and surrounding areas consist of six morphogenesis units are the volcanic origin, structural geology origin, denudation origin, kart origin, fluvial volcanic origin and alluvial origin. This region dominated by volcanic morphogenesis origin, the second is the structural geology origin, and the third is the fluvial volcanic origin. The morphogenesis fluvial volcanic origin showing a gentle slope and high intensity of erosion. Some places show the steep slope and potential landslide, especially along the rivers which are located in high land.

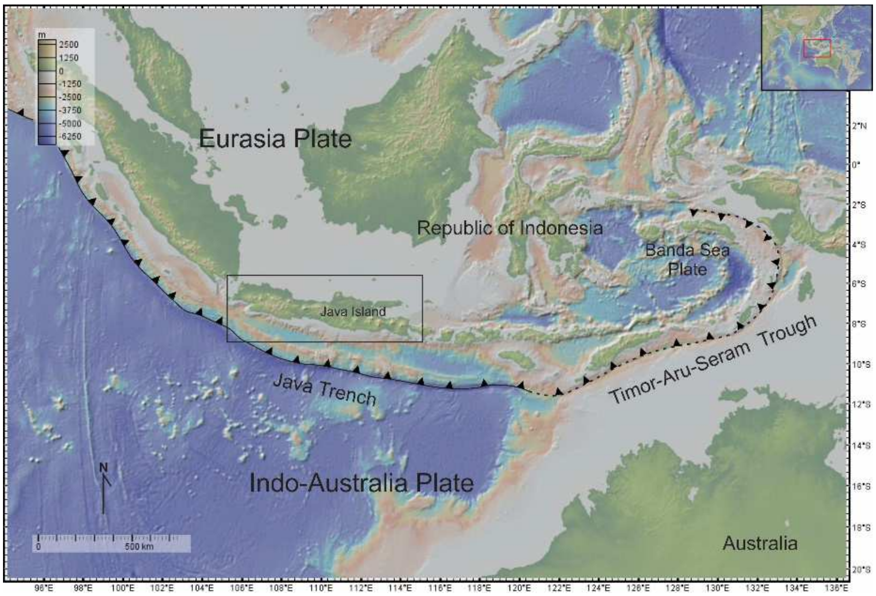

Figure 1. *Plate setting of Western Indonesia. A box shows location of Java Island and Tasikmalaya located area (see figure 2), Figure base made with topographic data from GeoMapApp [23].*

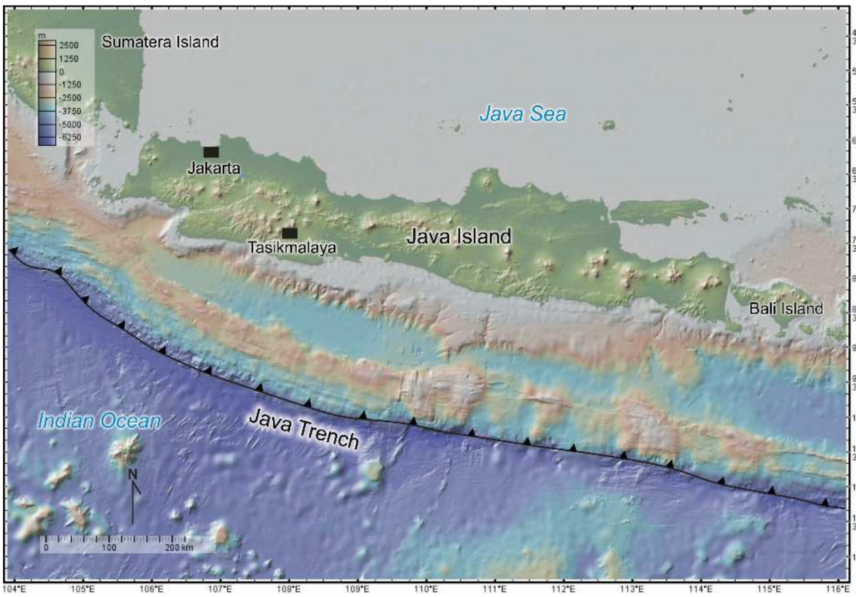

Figure 2. *Java Island and location of Tasikmalaya, Figure base made with topographic data from GeoMapApp [23].*

The Geology of Tasikmalaya and surrounding divided in to four units are the units of marine sediment, marine volcanic sediment, intrusion, and surface sediment [4]. Marine sediment unit consist of intercalation calcareous sandstone, claystone, marl, and limestones. Marine volcanic sediment unit consists of breccia, lava, and tuff. The unit intrusion rock are dacitic – granodiorite. These intrusion rocks are intruded the unit of marine sediment. The volcanic sediment in this region consist of volcanic breccia, tuff, and lava as the young volcanic product of Sawal, Tikukur, Cikuray, Galunggung, and Telagabodas volcanoes. Other surface sediments are the volcanic fans and river alluviums. The Structural geology consists of synclines, anticlines and faults. The axis of the anticlines and synclines are in the East-West direction. These anticlines and synclines shifted by right-lateral strike-slip fault.

We have been conducted research in the Tasikmalaya City surrounding area has 9 active faults and 5 potential active faults. The magnitude and the average slip of active faults and active potential are calculated based on the length of the segmentation using the empirical formula [11, 12, 15]:

1. Citandui active revers fault segment 1, length of fault 6 km, M=5.3 Mw, average displacement= 0.01cm.
2. Citandui active revers fault segment 2, length of fault 7 km, M= 5.4 Mw, average displacement 0.03 cm.
3. Citandui active revers fault segment 3, length of fault 8 km, M= 5.5 Mw, average displacement 0.06 cm.
4. Citandui active revers fault segment 4, length of fault 8.5 km, average displacement kekuatan 5.6 Mw, average displacement 0.08cm.
5. Citandui active revers fault segment 5, length of fault 7 km, M= 5.4 Mw, average displacement 0.03 cm.
6. Parungponteng potential active revers fault, length 12 km, M=5.9 Mw, average displacement 0.15 cm.
7. Bumirasa active right lateral strike slip fault, length 15 km, M= 5.9 Mw, average displacement 0.15 cm.
8. Sabtu active right lateral strike slip fault, length of fault 12.5 km, M= 5.8 Mw, average displacement 0.12 cm.
9. Sindangpalai active right lateral strike slip fault, length of fault 12 km, M= 5.7 Mw, average displacement 0.12 cm.
10. Cihanjuang active right lateral strike slip fault, length of fault 6 km, M= 5.2 Mw, average displacement 0.02 cm.
11. Ciwulan active right lateral strike slip active fault, leng of fault 13 km, M= 5.8 Mw, average displacement 0.13 cm.
12. Gunung Sigarnijah-Gunung Putu potensial active right lateral strike slip fault, length of fault 10.5 km, M= 5.6 Mw, average displacement 0.09 cm.
13. Kiaranonggeng potential active fault right lateral strike slip, length of fault 10.5 km, M=5.6 Mw, average displacement 0.09 cm.
14. Cibungur potential active right lateral strike slip fault, length of fault 6 km. M= 5.2 Mw, average displacement 0.02 cm.

The distribution of active and potential active faults in and around Tasikmalaya City shown in Figure 3.

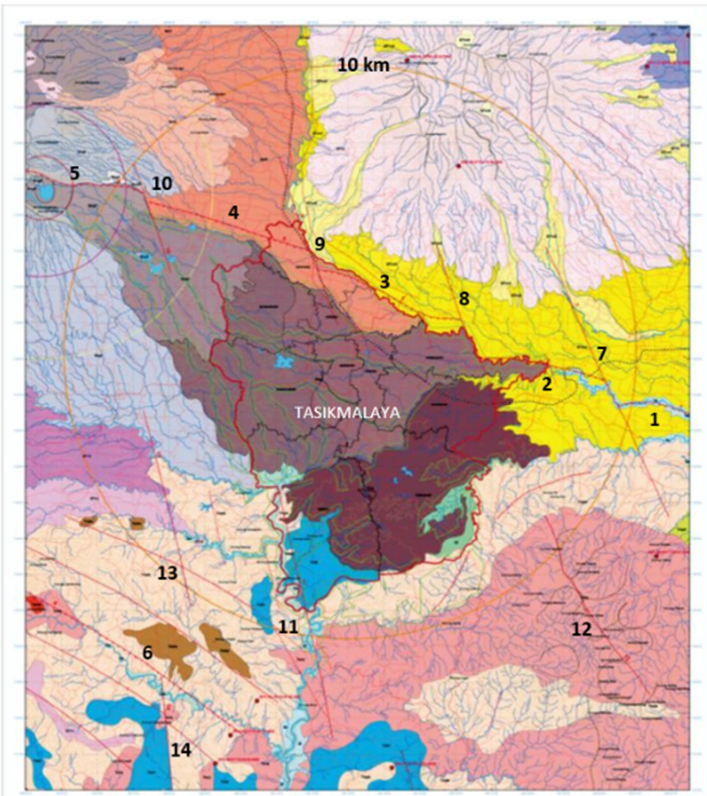

Figure 3. *Active and potential active faults distribution surrounding Tasikmalaya City.*

3. Microzonation of Tasikmalaya City

The intensity of ground shaking during an earthquake at a specific site depends not only on the magnitude and distance to the earthquake focus but also on the local geological conditions. Near-surface sedimentary layers can amplify seismic waves and lead to stronger shaking than nearby hard rock sites. A micro seismic zonation aims to outline zones of different potential shaking intensities using data of local soil conditions. The concept of microseismic zonation followed in this study is based on data from microtremor investigations to get information about the subsoil conditions of the survey area.

The two most important parameters that define the reaction of surface soft rock layers to shaking are layer thickness and shear-wave velocity (Vs) structure. A microtremor technique (single-station) allows estimating both parameters. The reaction to shaking is usually expressed utilizing an SH-transfer function. This function shows the relative amplification of shaking as a function of shaking frequency for a specific subsurface structure (layer thickness and Vs).

It is important to note that the amplification caused by the soil layer is frequency-dependent. To estimate how much damage a certain earthquake will cause to artificial structures at a specific site, one has to consider three components [13]:

1) the frequency spectrum of the earthquake at a hard rock site (source spectrum),
2) the frequency-dependent amplification of the subsoil (site effect),
3) the buildings' frequency-dependent reactions to shaking.

Microtremor techniques allow providing information for component (2), the SH-transfer function. Micro zonation maps prepared according to the concept presented here cannot provide specific information on components (1) or (3). The indication is relative hazard values related to component (2). The micro zonation map shows the hazard potential level at each site of the survey area as a single value. Therefore, it is required to derive a certain mean value of amplification from the frequency-dependent amplifications. At this point, also components (1) and (3) are considered: Information on these components can be found in the building code for Indonesia BSN SNI 1726:2019 [1, 5] in the form of site classes and design response spectra. In the BSN SNI 1726:2019 the shapes of the design response spectra are defined depending on the site class and site classes are defined based on shear-wave velocities of the top 30 m of soil (Vs30). Vs30 values can be derived from the microtremor data. In the concept described here, design response spectra are used as weighting functions for the SH-transfer functions before a mean amplification value is derived. This way, the design response spectra are defined by civil engineers as standards for designing buildings into the micro zonation map.

Microtremor mapping has been conducted by Centre of Geological Survey in the Tasikmalaya City on 15 until 28 May 2019 consists of 440 locations. The distance of each location is 500 m, and the measurement duration is 30 minutes. Map of microtremors distribution, shown in Figure 4.

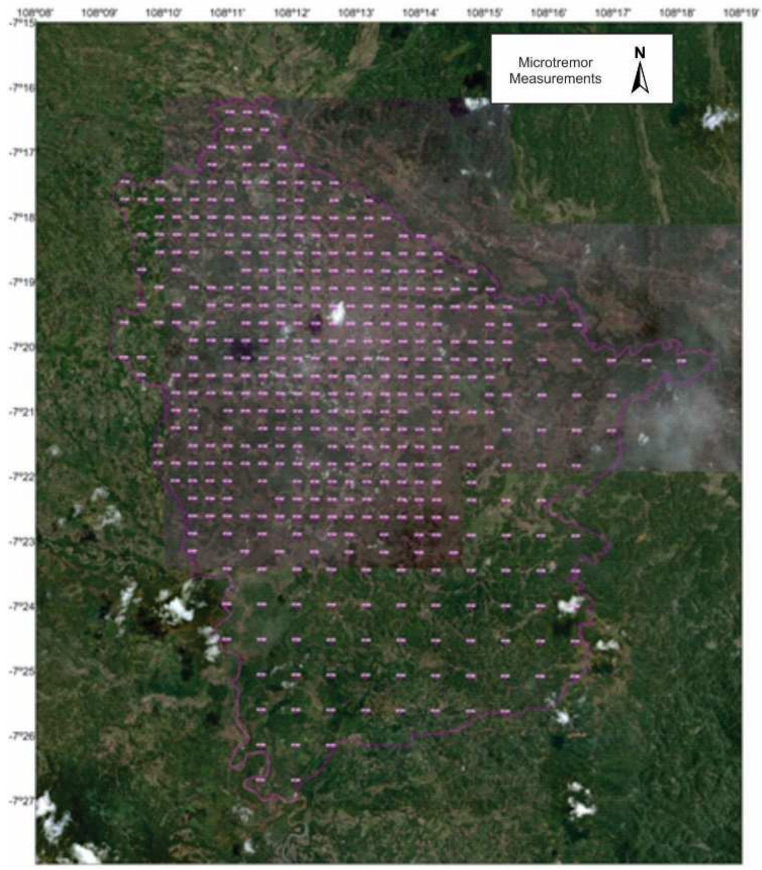

Figure 4. *Map of microtremor distribution of Tasikmalaya City.*

HVSR curves analyses were created using Geopsy Software [17, 18]. The HVSR curves calculation uses these parameters: using the bandpass filter 0.5 – 10 Hz, temporal window length 60 seconds, STA / LTA 0.1 – 2.5, and smoothing constant 40. The amplitude spectra of the NS and EW components were averaged by the quadratic mean method. Predominant frequency ($f0$) and amplification ($A0$) values were obtained for each curve then interpolated using the Inverse Distance Weighted method (IDW) to produce the predominant frequency and amplification. Inversion was carried out using Dinver package [6] to obtain the values of shear wave velocity (Vs) and layer thickness (h) underneath every station. One example of result analyses at M. 235 station [14] shown in Figure 5. The result of microtremor single-station mapping provides information on velocity structure, sediment thickness, and Vs30 values. SH-transfer functions can be calculated from these microtremor results.

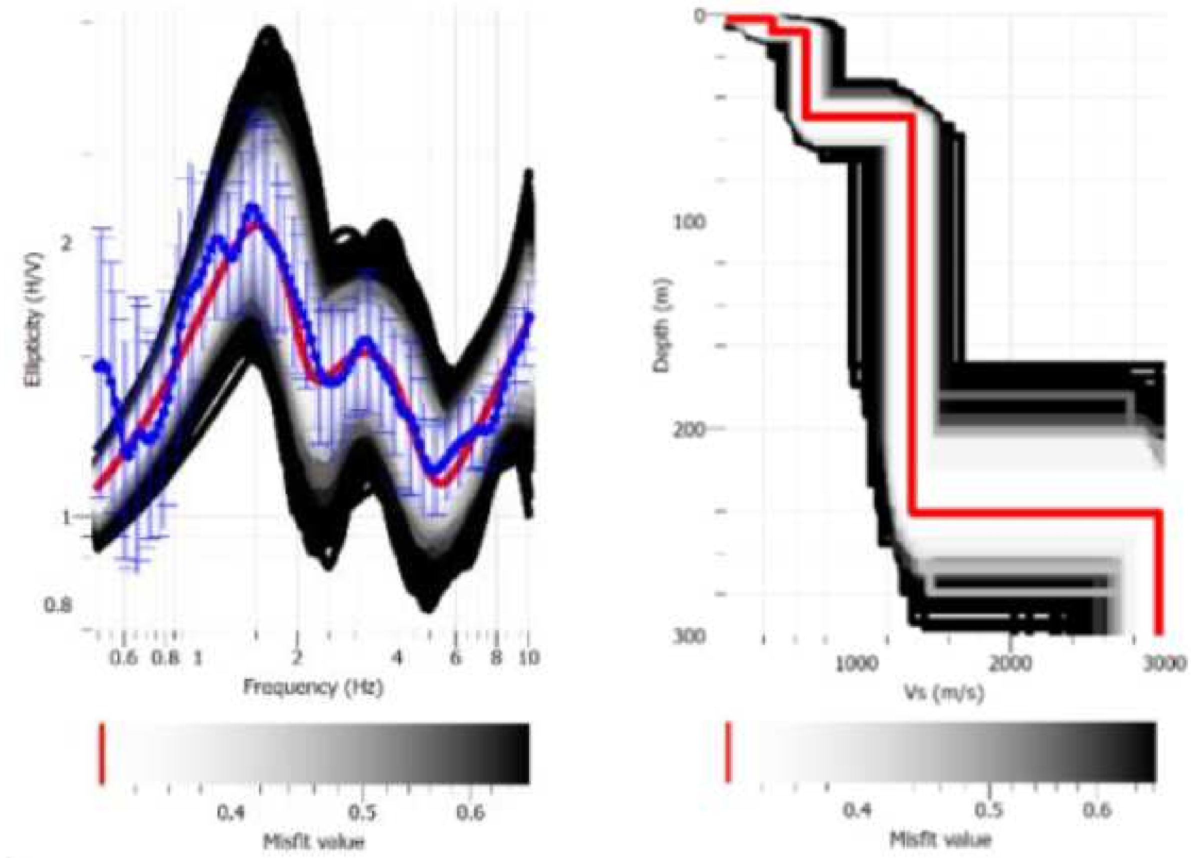

Figure 5. *Inversion results (M 235 station), (a) HVSR inversion curve, (b) Variation of Vs to depth [14].*

The micro zonation of the potential seismic hazard map of Tasikmalaya City has been made based on the Vs30 velocity and mean amplification values. Then, the whole of these values is statistically analyses to form three classes of relative potential seismic hazard (green, yellow, red). In the final step, a mean zone value can be derived for each district unit (Kecamatan) in Tasikmalaya City. Micro zonation map divided the city into three zonation of vulnerability which are High Potential Seismic Hazard (I/Red/, Vs30 < 175 m/sec amplification 2, site class SE), Medium Potential Seismic Hazard (II/yellow, Vs30= 175 – 350 m/sec, amplification 1, 5, site class SD) and Low Potential Seismic Hazard (III/green, Vs30= 350 – 750 m/sec, amplification 1, site class SC), the seismic hazard micro zonation map of Tasikmalaya City shown in Figure 6. To assess the potential seismic risk, we used the type of utilization and risk category in BSN, SNI 1726: 2019, which are divided into four risk categories, are the facilities that have a low risk to human life in case of failure (Risk Category I), the facilities that have medium risk to human of life in case of failure (Risk Category II), the facilities that have a high risk to human of life in case of failure (Risk Category III) and the essential facilities (Risk Category IV). Therefore, the risk mitigation strategy for this city, the region with a high vulnerability of seismic hazard, is recommended for Low to Medium Risk Category I and II. On the other hand, the region with low seismic hazard vulnerability is recommended for High-Risk Category III and IV.

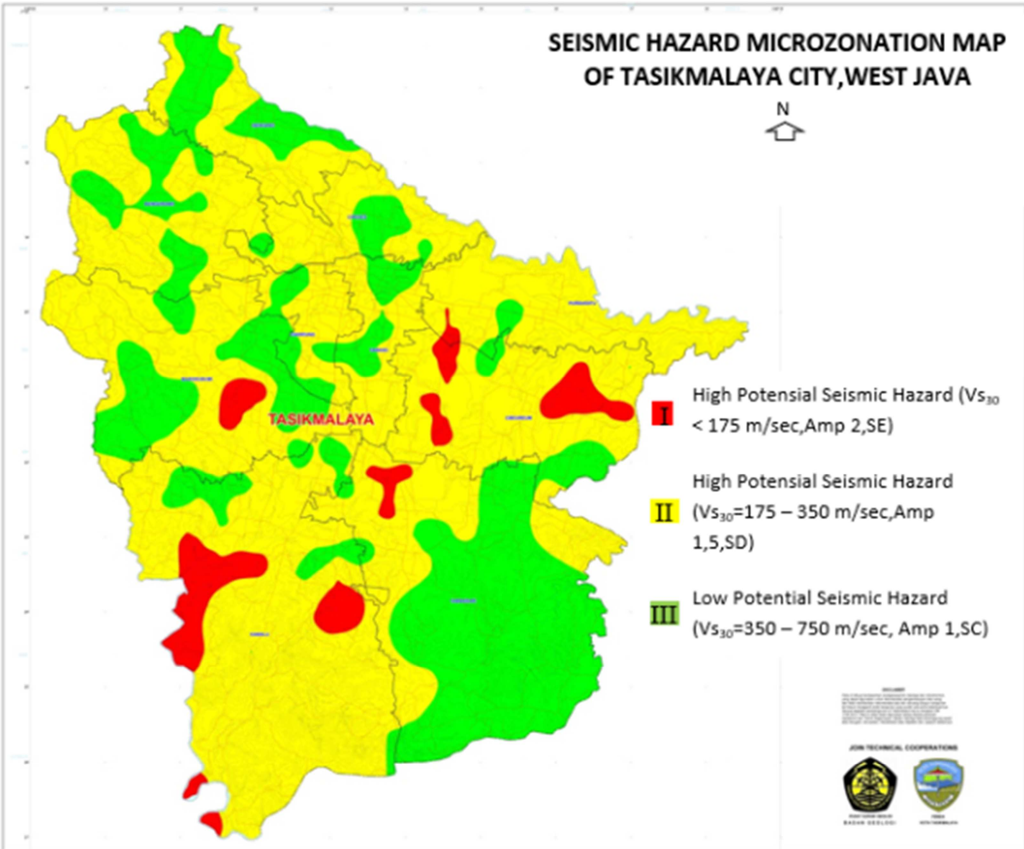

Figure 6. *Seismic hazard micro zonation map of Tasikmalaya City.*

4. Potential Seismic Hazard Assessment of Tasikmalaya City

Seismic source model is defined of Indonesia region, as a seismically homogenous area, in which every point within the source zone is assumed to have the same probability of being the epicenter of a future earthquake [10]. The Seismic Zonation Models [1] shows in Figure 5, were developed using earthquake catalogs, tectonic boundaries, and fault information, where composed of background seismicity, fault and subduction sources as recently developed by USGS for U.S. hazard map [16].

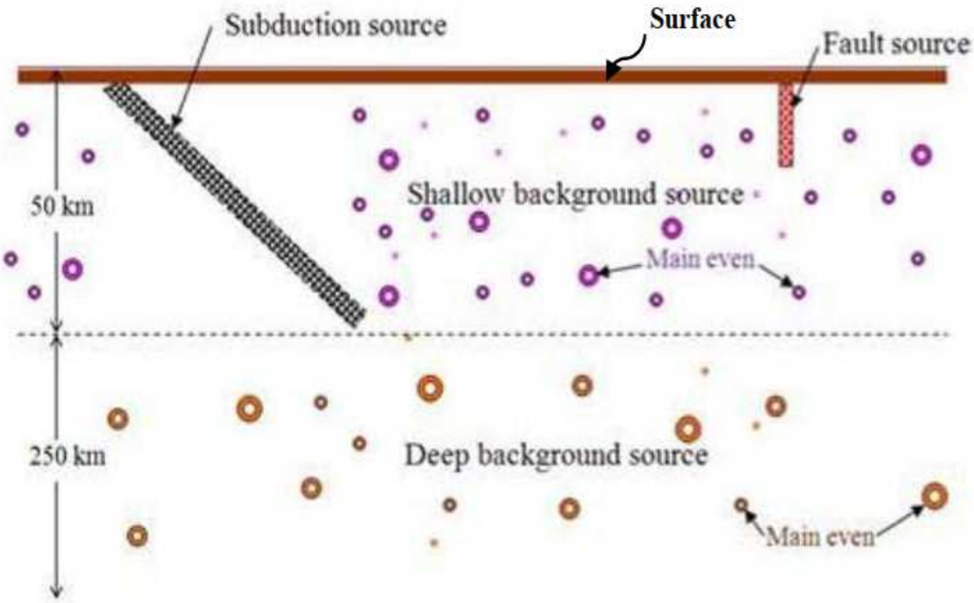

Figure 7. *Seismic source model as USGS proposed USGS [1].*

This model accounts for the observation that larger earthquakes (M ≥ 5) occur near smaller (M≥ 4 or 5) earthquakes. Gridded seismicity included in the model is based on earthquakes at five depth intervals: 0-50 km as shallow source, 50–100 km, 100–150 km, 150–200 km and 200–300 km as deep source model. The length of the mapped fault and down-dip width estimated from seismicity may be used to calculate maximum magnitudes of earthquakes expected to occur on these faults [19]. For determining magnitude from fault area or surface length on different segments or multi-segment ruptures the relations of Wells and Coppersmith [19] are used.

The major tectonic feature and type of faulting, slip-rate, dip, width and maximum magnitude are estimated based on published data. Subduction source model is the model of the seismic source, which represents the earthquake occurrence when plates are being subducted under an island arc or continent [1]. Information used as input parameters of this model include the location of subduction in the latitude and longitude coordinates, rate and b-value of the subduction area that can be obtained from the historical earthquake data with least square (GR) method [11]. This model was Limited to 50 km depth of the source rupture or Megathrust zones, deeper zones or Benioff zones are represented by deep background source models [1].

Attenuation relations trend to be regionally specific, unfortunately there is no attenuation specifically developed for Indonesia region [1]. Indonesia PSHA analyses to adapt attenuation function derived in other region, which is similar to Indonesia region tectonically and geologically. It is of importance that the selection was based on earthquake mechanism, which is generally categorized into background, fault and subduction source zones [1]. Some attenuation relationships have used Next Generation Attenuation (NGA) as a comparison are listed:

a. Attenuation for Shallow Background:
   1. Boore-Atkinson NGA [6].
   2. Campbell-Bozorgnia NGA [7].
   3. Chiou-Young NGA [9].
b. Attenuation for Deep Background Sources:
   1. Atkinson-Boore intraslab Puget Sound region BC-rock condition [2].
   2. Geomatrix slab seismicity rock [20].
   3. Atkinson-Boore intraslab seismicity world data BC-rock condition [3].
c. Attenuation for Fault Sources:
   1. Boore-Atkinson NGA [6].
   2. Campbell-Bozorgnia NGA [7].
   3. Chiou-Young NGA [9].
d. Attenuation for Subduction Sources:
   1. Geomatrix subduction [20].
   2. Atkinson-Boore BC rock and global Source [3].
   3. Zhao et al with variable Vs-30 [21].

In order to analyses the PSHA of Indonesia region, some researchers made a logic-tree model, for example, Coppersmith and Youngs [8] is used in this analyses in order to allow uncertainties in selection of models for recurrence model, maximum magnitude and attenuation function to be considered. The probabilistic seismic hazard maps of Indonesia as the result of the analyses are shown in Figures 8, 9 and 10.

The probabilistic seismic hazard map of Indonesia (BSN, SNI 1726-2019), shows the Tasikmalaya City located at the region of Peak Ground Acceleration (PGA)= 0.4 – 0.5 g, Pseudo Spectral Acceleration (PSA $S_{S:0,2\ second}$)= 0.7 – 0.8 and Pseudo Spectral Acceleration (PSA $S_{1:\ 1\ second}$)= 0.4 – 0.5, for Soil Class SB, 2% probability in 50 years.

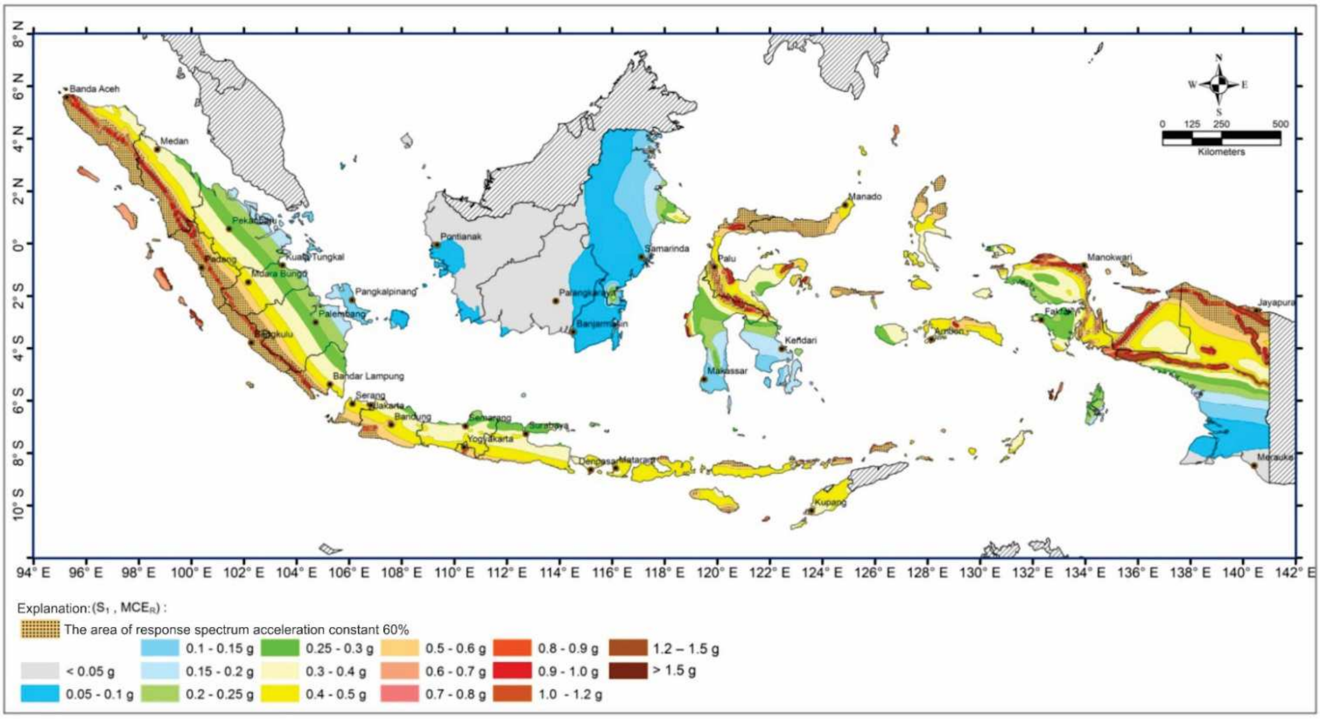

Figure 8. *Peak ground acceleration (PGA) map of Indonesia [5].*

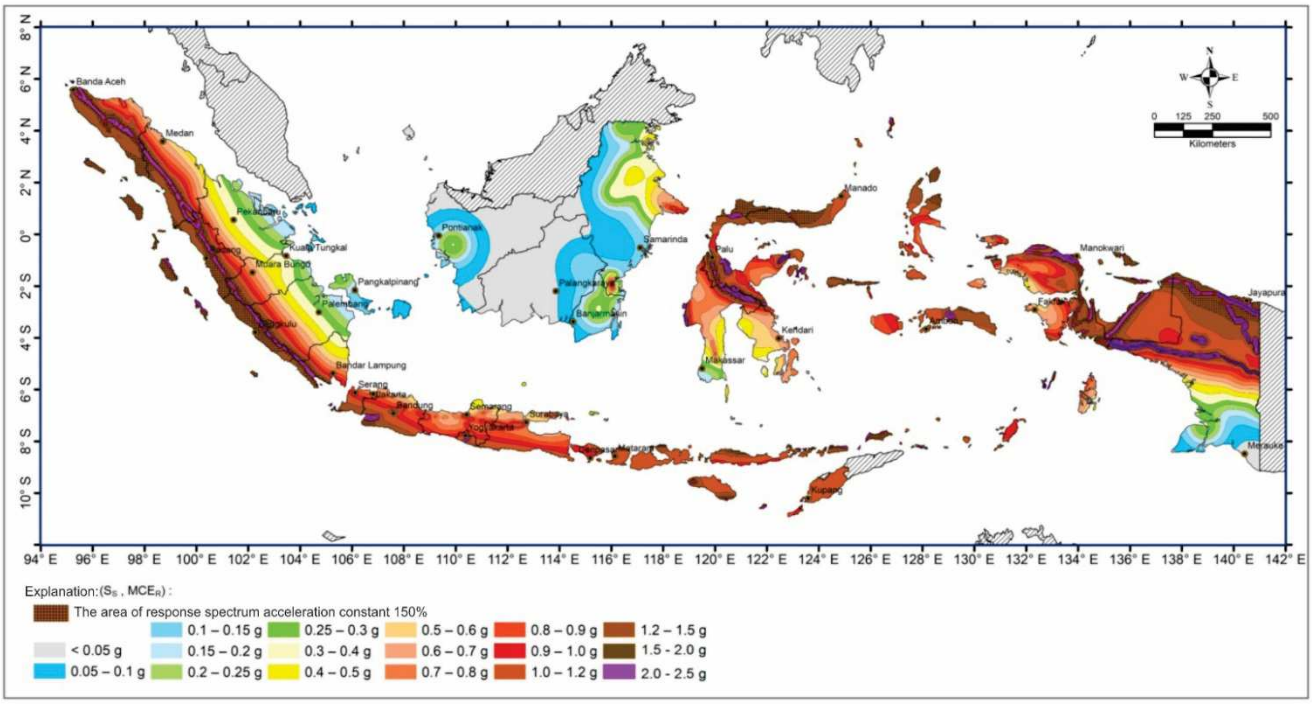

Figure 9. *Pseudo spectral acceleration (PSA $S_{s=0,2\ second}$) map of Indonesia [5].*

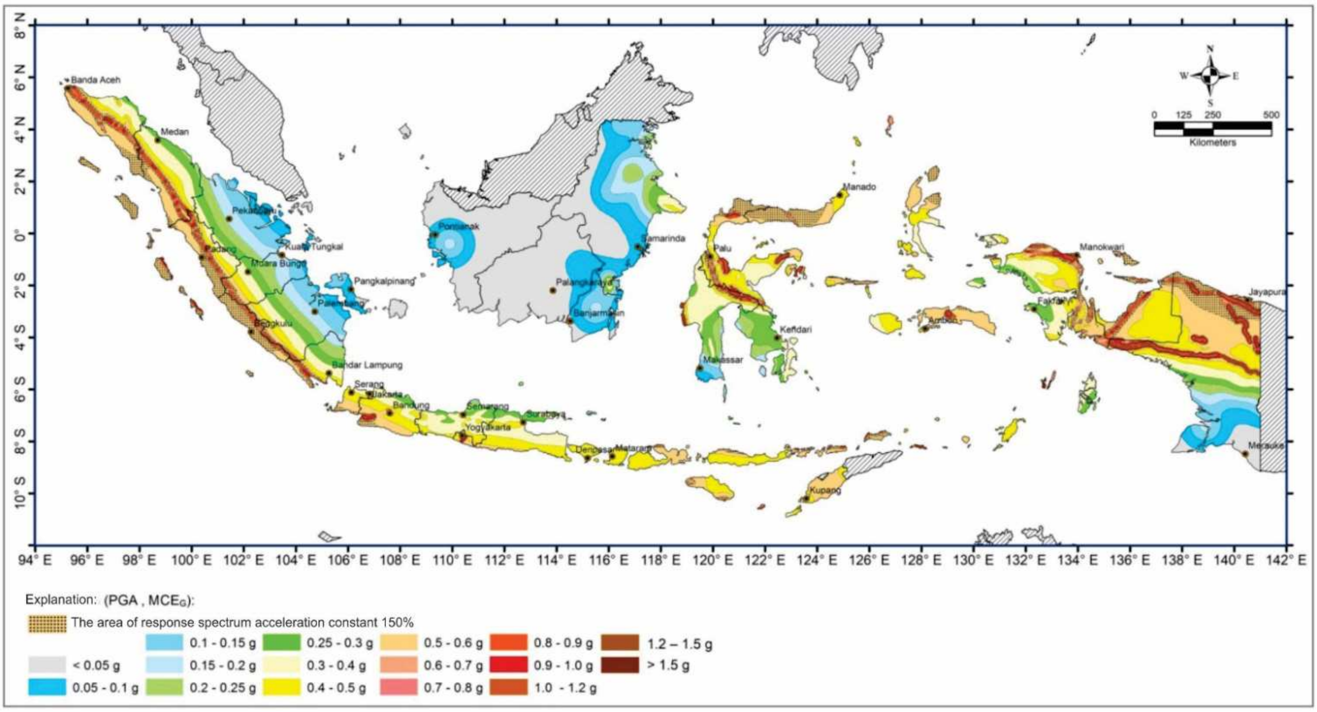

Figure 10. *Pseudo spectral acceleration (PSA $S_{1=1\ second}$) map of Indonesia [5].*

Table 1. *Response spectral parameters for short period of earthquake S_s [2].*

Site Class	Maximum response spectral accelaration parameters for short period S_S = 0.2 sec (MCE_R)					
	Ss≤0.25	Ss=0.5	Ss=0.75	Ss=1.0	Ss=1,25	ss≥1.5
SA	0.8	0.8	0.8	0.8	0.8	0.8
SB	0.9	0.9	0.9	0.9	0.9	0.9
SC	1.3	1.3	1.2	1.2	1.2	1.2
SD	1.6	1.4	1.2	1.1	1.0	1.0
SE	2.4	1.7	1.3	1.1	0.9	0.8
SF	SS[(a)]					

Table 2. *Response spectral parameters for long periode of earthquake S_1 [2].*

Site Class	Response spectral paramaters for long periode of earthquake S_1=1sec (MCE_R)					
	$S_1 \le 0.1$	S_1=0.2	S_1=0.3	S_1=0.4	S_1=0.5	$S_1 \ge 0.6$
SA	0.8	0.8	0.8	0.8	0.8	0.8
SB	0.8	0.8	0.8	0.8	0.8	0.8
SC	1.5	1.5	1.5	1.5	1.5	1.4
SD	2.4	2.2	2.0	1.9	1.8	1.7
SE	4.2	3.3	2.8	2.4	2.2	2.0
SF	SS(a)					

Table 3. *Seismic desain category base on accelaration response parameter for short period of earthquake 0, 2 second [2].*

S_{DS} Value	Risk Category	
	I or II or III	IV
$S_{DS} < 0.167$	A	A
$0.167 \le S_{DS} < 0.33$	B	C
$0.33 \le S_{DS} < 0.50$	C	D
$0.50 \le S_{DS}$	D	D

Table 4. *Seismic desain category base on accelaration response parameter for long period of earthquake 1 second [2].*

SD_1 Value	Risk Category	
	I or II or III	IV
$S_{D1} < 0.067$	A	A
$0.067 \le S_{D1} < 0.133$	B	C
$0.133 \le S_{D1} < 0.20$	C	D
$0.20 \le S_{D1}$	D	D

Table 5. *Ground shaking parameters for site class SE in Tasikmalaya City.*

Parameters	Value (g)
S_S	0.80
S_1	0.50
S_{MS}=Fa S_S=1.3 X 0.80	1.04
S_{M1}=Fv. S_1=0.8 X 0.50	0.40
S_{DS} = 2/3 S_{MS}	0.69
S_{D1} =2/3 S_{M1}	0.27
T_0 = 0,2 (S_{D1}:S_{DS})	0.08 sec
T_S = (S_{D1}:S_{DS})	0.39 sec

Table 6. *Spectral elastic desain for building and non building at site class SE in Tasikmalaya City.*

Period, T(S)	Spectrak Accelation, Sa (g)
0	0.28
0.08 (=T0)	0.69
0.39 (=Ts)	0.69
1	0.27
2	0.14
3	0.09
4	0.07
5	0.05
6	0.04

In order to determine the building and non-building of risk and seismic design category in each zonation, has been done the seismic hazard and risk assessment base on PSA and the zonation of site class. There are four provisions [5] used to assess the potential seismic hazard and risk in order to determine the structure of seismic design category, as shown in Tables 1, 2, 3, and 4.

The potential seismic hazard and risk assessment in Tasikmalaya City is shown in Tables 5-10 and Figures 9, 10 and 11. The result of ground acceleration, risk and seismic desain categories assessment of each zonation shown in Table 11.

Table 7. *Ground shaking parameters for site class SD in Tasikmalaya City.*

Parameters	Value (g)
S_S	0.80
S_1	0.50
S_{MS}=Fa S_S=1.2X0.80	0.96
S_{M1}=Fv. S_1=1.8 X 0.50	0.90
S_{DS} = 2/3 S_{MS}	0.64
S_{D1} =2/3 S_{M1}	0.60
T_0 = 0,2 (S_{D1}:S_{DS})	0.19 sec
T_S = (S_{D1}:S_{DS})	0.94 sec

Table 8. *Spectral elastic desain for building and non building at site class SD in Tasikmalaya City.*

Period, T(S)	Spectral Accelation, Sa (g)
0	0.26
0.19 (=T0)	0.64
0.94 (=Ts)	0.64
1	0.60
2	0.30
3	0.20
4	0.15
5	0.12

Table 9. *Ground shaking parameters for site class SC in Tasikmalaya City.*

Parameters	Value (g)
S_S	0.80
S_1	0.50
S_{MS}=Fa S_S=1.2 X0.80	0.96
S_{M1}=Fv. S_1=1.5 X 0.50	0.75
S_{DS} = 2/3 S_{MS}	0.64
S_{D1} =2/3 S_{M1}	0.50
T_0 = 0,2 (S_{D1}:S_{DS})	0.16 sec
T_S = (S_{D1}:S_{DS})	0.78 sec

Table 10. *Spectral elastic desain for building and non building at site class SC in Tasikmalaya City.*

Period, T(S)	Spectral Accelation, Sa (g)
0	0.26
0.16 (=T0)	0.64
0.78 (=Ts)	0.64
1	0.50
2	0.25
3	0.17
4	0.13
5	0.10
6	0.08

Table 11. *Ground Accelaration, Risk and Seismic Desain Categor Assessment of Tasikmalaya City.*

Seismic Hazard Zonation	S_s	S_1	S_{DS}	Risk Category	Seismic Desain Category	S_{D1}	Risk Category	Seismic Desain Category
I/Red, SE, Amp 2	0.80g	0.50g	0.69g	I, II, III, IV	D	0.27g	I, II, III, IV	D
II/Yellow, SD, Amp 1.5	0.80g	0.50g	0.64g	I, II, III, IV	D	0.60g	I, II, III. IV	D
III/Green, SC, Amp 1	0.80g	0.50g	0.59g	I, II, III, IV	D	0.50	I, II, III, IV	D

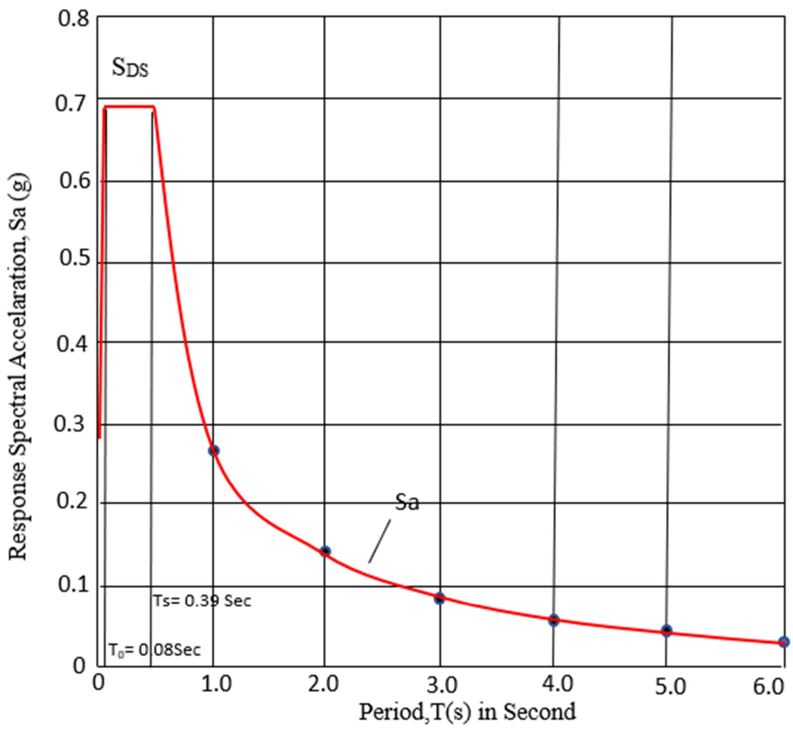

Figure 11. *Response of elastic desain spectra for building and non building in Tasikmalaya City, at site class SE with S_s= 0.80 g and S_1 = 0.50 g.*

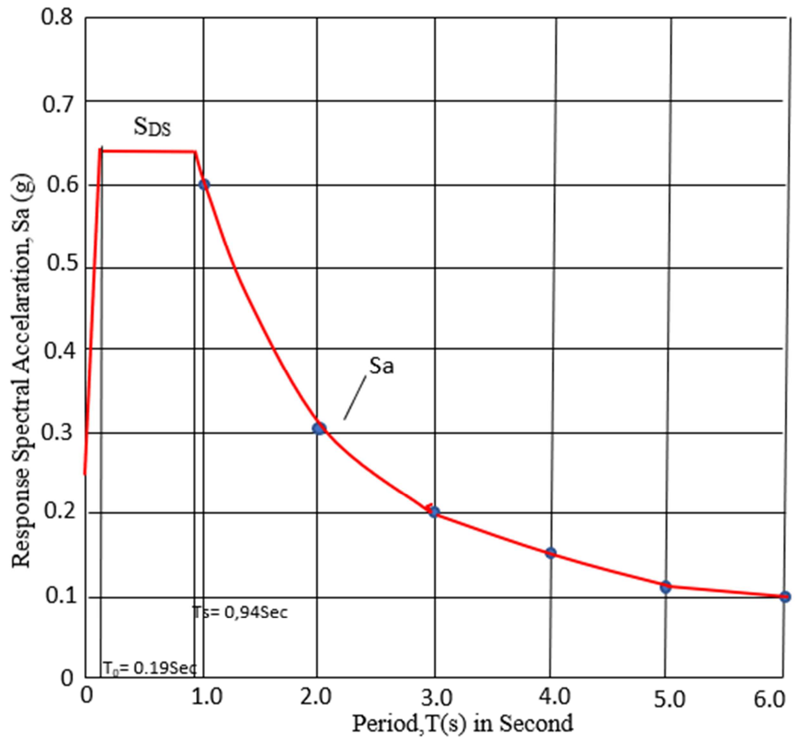

Figure 12. *Response of elastic desain spectra for building and non building, at site class SD in Tasikmalaya City with S_s= 0.80 g and S_1 = 0.50 g.*

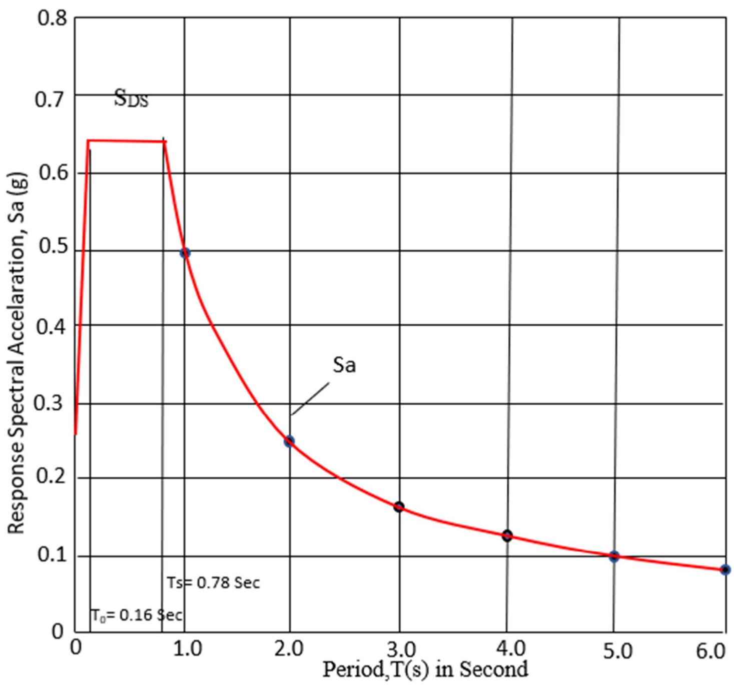

Figure 13. *Response of elastic desain spectra for building and non building at site class SC in Tasikmalaya City with S_s= 0.80 g and S_1 = 0.50 g.*

5. Conclusion

The Tasikmalaya City and its surroundings is seismically an earthquake disaster-prone area in West Java. Buildings and non-buildings in this city which are located in high, medium and low earthquake vulnerability zone must be built with a structure with seismic design category D in accordance with BSN SNI 1726:2019 [5]. Buildings and non-buildings do not have this category should be strengthened. Socialization on the application of earthquake-resistant buildings should be carried out in this city.

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