IOP Conference Series: Earth and Environmental Science

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To cite this article: A S Bawono *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **366** 012014

A Comparison Method for Calculating Ground Shaking Case study: Yogyakarta Earthquake 2006

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Abstract. This paper presents a comparison method for calculating ground shaking in Yogyakarta, especially in Sedayu Permai Housing, Bantul District. The study was based on Hazard US (HAZUS) with Ground Motion Prediction Equations. The suitable using the latest attenuation equation from [1] for the BC class site rock and global source subduction use. Therefore, is needed necessary from an experts' judgment to evaluate because different mechanism of earthquake for Indonesian seismic hazard.

Keywords: Ground Motion, HAZUS, Yogyakarta Earthquake

1. Introduction

Earthquake risk assessment is a combination of the earthquake/seismic hazard and vulnerability. Earthquake hazard is the probability of occurrence of a potentially damaging earthquake, characterised as being an individual event out of human control. The vulnerability that occurs can result in the amount of damage to the building as a consequence of the occurrence of earthquake hazards with a certain intensity. Also, earthquake hazard event parameter on the earthquake zone area. Earthquake vulnerability depends upon model building type, and damage state effected from the hazard. It can depict in the equation R = H x V / C, where R is a risk, H is a hazard, V is a vulnerability, and C is capacity [1]. It is well understood that it is not the earthquake which kills but the failure of the buildings exposed to these earthquakes [3-5].

In seismic hazard analysis, Ground Motion Predictions (GMP) in an earthquake zone area need to be carried out by the latest developments in seismic science and technology. GMP needs to be done, in order to be able to represent functions related to earthquake source information, earthquake wave propagation pathways, and location conditions of observation points. Contrary, with the knowledge of earthquake source information, earthquake wave propagation lines, and observation point conditions, can minimise the risk of loss of life and property losses due to the earthquake hazard.

Many researchers have been estimated and predict ground motion by many methods [6-11], but Hazard US (HAZUS) model is the most especially in the United States of America (USA) and Europe [5, 12-14]. Research on the seismic hazard analysis to estimated and predict ground motion need much data for seismicity, seismic sources and site conditions, except Indonesia. Therefore, the objective of this study was to the identified compatibility of the ground motion methodology HAZUS model between 3 (three) methods differences, there are: basis for ground shaking use supplied seismic hazard maps, standard shape of response spectra for period 0,3 and 1 second, attenuation of ground shaking in

Indonesia. An evaluation is needed to keep up with the latest developments in seismic science and technology.

2. The General Background

2.1 Indonesia Earthquake/Seismic Hazard

Disasters in Indonesia during 1982-2012 caused 225,509 people to disappear and die. This victim was caused by various types of disasters that occurred, among others, 174,101 earthquakes and tsunamis, 15,250 earthquakes, floods and 7,555 landslides and 28,603 other disasters. The most are an earthquake hazard. Geographically Indonesia is located in a series of rings of fire that stretch along the Pacific plate which is the most active tectonic plate in the world. Zone this contributes nearly 90% of earthquake events on earth and almost everything is a big earthquake in the world. Seismic conditions in Indonesia are strongly influenced by four (4) major tectonic plates, the Eurasian plate, Indo-Australia, the Pacific and the Philippines [15].

2.1.1 Earthquake/Seismic Zone Area

Earthquake events often occur in Indonesia, one of the sources of the earthquake that occurred was the active subduction zone starting from west to east Indonesia, besides that because of the remaining energy from tectonic plate collisions which resulted in faults on land and sea on several islands in Indonesia. Earthquake events often occur in Indonesia, one of the sources of the earthquake that occurred was because of the active subduction zone starting from west to east Indonesia, also because of the residual energy from tectonic plate collisions which resulted in faults on land and sea on several islands in Indonesia.

Subduction zones with MW (7-8) were identified in Western Sumatra in 2004 (Aceh earthquake), 2005 (Nias earthquake) and 2010 (Mentawai earthquake); in South Java in 1997 (Pacitan Earthquake), 2006 (Pangandaran Earthquake); in Sulawesi and around Halmahera island in 2014 (Sangihe Earthquake). According to National Geographic, the earthquake incident stated that the Aceh earthquake was the second worst disaster with a loss of more than 220,000 and economic losses reaching 10 Billion USD, due to a tsunami.

Meanwhile, the next worst earthquake event was the Yogyakarta earthquake in 2006 which caused 6,234 deaths, while 36,299 people have been injured, 135,000 houses damaged, you estimated more than 600,000 left homeless, due to subduction due to subduction between Indo Australia plates and Eurasia [16].

2.1.2 Earthquake/Seismic Hazard Analysis

Assuming that a destructive earthquake will occur and take place in an active fault zone, or close to past earthquakes, and ground shaking or vibration will approach the level of the earthquake in the past. Probabilistic Seismic Hazard map (PSHA) is an effective method to determine the distribution of potential shocks and a reliable basis for estimating risks in an existing residential area or infrastructure [16-18]. PSHA is a standard method used in earthquake engineering. This PSHA method provides explicit space to calculate epistemic uncertainties and deviations from several input model components used to estimate seismic hazards which include earthquake sources and ground motion prediction [16]. The HAZUS Methodology includes maps for eight probabilistic hazard levels: ranging from ground shaking with a 39% probability of being exceeded in 50 years (100 year return period) to the ground shaking with a 2% probability of being exceeded in 50 years (2500 year return period) [20].

2.2 Ground Motion

Ground motion estimates are generated in the form of Geographic Information System (GIS)-based contour maps and location-specific seismic demands stored in relational databases. Ground motion is characterized by: (1) spectral response, based on a standard spectrum shape, (2) peak ground acceleration and (3) peak ground velocity. The spatial distribution of ground motion can be determined using one of the following methods or sources: Deterministic ground motion analysis (Methodology calculation), United States Geological Survey (USGS) probabilistic ground motion maps (maps supplied with HAZUS), other probabilistic or deterministic ground motion maps (user-supplied maps) provided.

The description of the methods for calculating ground shaking divided into 5 (five) separate areas: basis for ground shaking, the Standard shape of response spectra, Attenuation of ground shaking, Distance measurement used with attenuation relationships, Amplification of ground shaking - local site conditions. This paper compares between 3 (three) methods, there are: basis for ground shaking use supplied seismic hazard maps, standard shape of response spectra for period 0,3 and 1 second, attenuation of ground shaking.

2.2.1 User-Supplied Seismic Hazard Maps

HAZUS using Uniform Building Code (UBC) and National Earthquake Hazard Reduction Program (NEHRP) provisions earthquake zone map for getting seismic design code. In UBC earthquake zone map, there are earthquake zone and value of Peak Ground Acceleration (PGA) (HAZUS also provides convenience in determining earthquake areas [21].

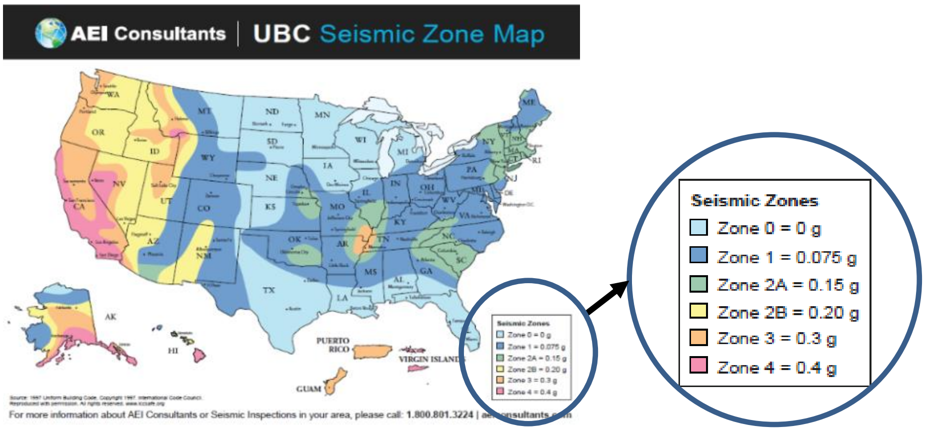


Figure 1. UBC Earthquake Zone Map [21]

2.2.2 Standard Shape of the Response Spectra

The methodology characterizes ground shaking using a standardized response spectrum shape. The standardized shape consists of four parts: Peak Ground Acceleration (PGA), a region of constant spectral acceleration at periods from zero seconds to TAV (seconds), a region of constant spectral velocity at periods from TAV to TVD (seconds) and a region of constant spectral displacement for periods of TVD and beyond. Spectral acceleration plotted as a function of spectral displacement (rather than as a function of the period) [13].

2.2.3 Attenuation of ground shaking

Ground shaking is attenuated with distance from the source using relationships provided with the methodology. Ground motion estimation is a sophisticated combination of earth science, engineering and probabilistic methods and should not be attempted by users, including local geotechnical engineers, who not have the proper expertise. For users who do not have the expertise to estimate ground motion and who need guidance on which existing attenuation function to use, the table below summarizes the 59 choices that currently exist within HAZUS. Note that the dependent attenuation functions are the cocktail-based ones in HAZUS.

2.3 Yogyakarta Earthquake

Data of Yogyakarta Earthquake on May 27, 2006 given from [22]. The magnitude which hit Central Java and Yogyakarta Province in Indonesia is Mw 6.3 at time 5:54 local time, an earthquake causing widespread destruction and loss of life and property. The location coordination of the epicenter in 7.962oS and 110.458oE, according to the United States Geological Survey (USGS) its about 20 km from Yogyakarta City. Whereas the tectonic setting is that of significant subduction of the Indo-Australian plate under Eurasia, with the region affected being on the Sunda micro-plate, fault plane solutions indicated a left-lateral strike-slip mechanism is trending North East (NE) – South West (SW).

Two attenuation relationships by [23-24] are employed to assess the severity of motion in this earthquake, and to construct iso-acceleration plots. The latter two relations hips are selected because they pertain to strike-slip and thrust mechanisms, large magnitude, and a large and uniformly processed data base. Whereas some reports implicate the Opak Fault in the earthquake, this has not been conclusively confirmed, and nothing is known as to the initiation, propagation or extent of faulting at the time of publication of this report. No conclusive evidence of the surface manifestation of the fault exists, to the satisfaction of the Mid-American Center (MAE Center) Team, and no evidence linking the eruption of Mount Merapi volcano that preceded the 27 May 2006 earthquake [22].

In Yogyakarta Province there are 5 Regencies, namely Sleman, Gunungkidul, Kulonprogo, Bantul and Yogyakarta. The largest damaged area was Bantul district where 31 people were dead, 564 get injured and 2,682 houses were collapsed and 8,316 houses damaged, including in Sedayu sub district there are 1,250 houses were extensive/collapsed damaged, 838 houses was moderately damaged, and 4,591 house were slight damaged [25].

3. Methodology

3.1 User-Supplied Seismic Hazard Maps

The research method uses the UBC 1997 map (Figure 1) as guidelines, and from UBC can know the value of PGA and zone level of earthquake.

3.2 Standard shape of response spectra

From the seismic zone map Indonesia which established in the year 2010 and 2017 by the PU which can get PGA and drawn Spectrum Response. In 2011, The Ministry of Public Works-Center for Research and Development of Housing and Settlements (PU PUSKIM) had established the website-*based* application Indonesia design spectra to calculate response spectrum, based on Seismic Zone Map Indonesia 2010.

3.3 Attenuation of ground shaking

The attenuation relationships cannot be evaluated since the sufficient strong ground motion records are not available for this region, including in Yogyakarta and Central Java. Therefore, the attenuation relations which were developed for other territories as Europe and Japan are used for the present hazard calculation by validating, using the aftershocks records, modeling the peak ground acceleration maps for the recent event, 27 May, 2006, Yogyakarta earthquake inserting the damage area distribution pattern [11].

The attenuation relationships in HAZUS provided with the Methodology include all five of the Next Generation Attenuation (NGA) Models developed for the Western United States (WUS) and seven Ground-Motion Prediction equations (GMPEs) for the Central and Eastern United States (CEUS). It is expected by late 2012/early 2013 that the NGA Models will be developed/finalized for CEUS and therefore will be available to include in HAZUS as well.

3.3.1 HAZUS Attenuation Equation

There are 14 ground motion relation proposed for use by HAZUS to model ground motions and identifies the applicable region(s), the number of different types of faulting modeled by each relation, and the definition(s) of fault distance parameter used by each relation. The three new NGA ground motion relations are [1, 26-27]. For users who don’t have the expertise to estimate ground motion and who need guidance on which existing attenuation function to use, the table below summarizes the 59 choices that currently exist within HAZUS [20].

Table 1. Attenuation equation for expert-generated ground motion estimation [20]

Attenuation Function #	Description	Fault Mechanism	East or West US	Note
1	Toro et al. (1997)	E	E	
2	Frankel (1996)	E	E	
3	Campbell (2003)	E	E	
4	Atkinso and Boore (2006)	E	E	
5	Tavakoli_Pezeshk (2005)	E	E	
6	Silva et al (2002)	E	E	
7	Somerville (2002)	E	E	
8	NGA - Boore &Atkinson (2008) - Strike Slip	S	W	
9	NGA - Boore &Atkinson (2008) - Reverse	R	W	
10	NGA - Boore &Atkinson (2008) - Normal	N	W	
11	NGA - Chiou & Youngs (2008) - Strike Slip	S	W	
12	NGA - Chiou & Youngs (2008) - Reverse	R	W	
13	NGA - Chiou & Youngs (2008) - Normal	N	W	
14	NGA - Campbell & Bozorgnia (2008) - Strike Slip	S	W	
15	NGA - Campbell & Bozorgnia (2008) - Reverse	R	W	
16	NGA - Campbell & Bozorgnia (2008) - Normal	N	W	
17	NGA - Abrahamson & Silva (2008) - Strike Slip	S	W	
18	NGA - Abrahamson & Silva (2008) - Reverse	R	W	
19	NGA - Abrahamson & Silva (2008) - Normal	N	W	
20	Cascadia - Youngs et al. (1997) - Interslab	F	W	
21	Cascadia - Youngs et al. (1997) - Interface	I	W	
22	Atkinson & Boore, Global (2002) - Interslab	F	W	
23	Atkinson & Boore, Global (2002) - Interface	I	W	
24	Atkinson & Boore (2002), Regional - Interslab	F	W	
25	Atkinson & Boore (2002), Regional - Interface	I	W	
26	Zhao and Others (2006) - Interslab	F	W	
27	Zhao and Others (2006) - Interface	I	W	
28	Central & East US (CEUS 2008)	E	E	
29	CEUS, New Madrid Seismic Zone (NMSZ 2008)	E	E	Dependent
30	CEUS, Charleston 2008	E	E	Dependent
31	West US, Coastal California (2008) - Strike Slip	S	W	Dependent
32	West US, Coastal California (2008) - Reverse	R	W	Dependent
33	West US, Coasltal - Normal	N	W	Dependent
34	West US, Extensional 2008 - Strike Slip	S	W	Dependent
35	West US, Extensional 2008 - Reverse	R	W	Dependent
36	West US, Extensional 2008 - Normal	N	W	Dependent
37	West US, Non - Extensional 2008 - Strike Slip	S	W	Dependent
38	West US, Non - Extensional 2008 - Reverse	R	W	Dependent
39	West US, Non - Extensional 2008 - Normal	N	W	Dependent
40	West US, inter- Mountain West - Strike Slip	S	W	Dependent
41	West US, inter- Mountain West - Reverse	R	W	Dependent

Attenuation Function #	Description	Fault Mechanism	East or West US	Note
42	West US, inter- Mountain West - Normal	N	W	Dependent
43	West US, Wasatch 2008 - Strike Slip	S	W	Dependent
44	West US, Wasatch 2008 - Reverse	R	W	Dependent
45	West US, Wasatch 2008 - Normal	N	W	Dependent
46	Pacific Northwest (PNW 2008) - Strike Slip	S	W	Dependent
47	Pacific Northwest (PNW 2008) - Reverse	R	W	Dependent
48	Pacific Northwest (PNW 2008) - Normal	N	W	Dependent
49	Cascadia - Subduction / Interface (2008)	F	W	Dependent
50	Cascadia - Subduction / Interslab (2008)	I	W	Dependent
51	Alaska or Puerto Rico / VI - Strike Slip	S	W	Dependent
52	Alaska or Puerto Rico / VI - Reverse	R	W	Dependent
53	Alaska or Puerto Rico / VI - Normal	N	W	Dependent
54	Alaska or Puerto Rico / VI - Subduction / Interslab	F	W	Dependent
55	Alaska or Puerto Rico / VI - Subduction / Interface	I	W	Dependent
56	Hawaii - Reverse	R	W	Dependent
57	Hawaii - Volcanic/Shallow	N	W	Dependent
58	Hawaii - Volcanic/Deep	N	W	Dependent
59	Hawaii - Munson and Thurber (1997)	N	W	

3.3.2 Yogyakarta and Java Subduction Attenuation

The attenuation relationships due to the May 27, 2006 Yogyakarta Earthquake continues to be examined starting from equation relationships with 1) [23-24] in [22,28]; 2) [29-30]; 3) the results of a study conducted by [31] showed that for the source of subduction earthquakes, the Ground Motion Prediction Equation (GMPE) equation of [37], [3], and [38] matched the acceleration data from Java (include Yogyakarta and Central Java) and Sumatra; and 4) the newest attenuation relationships in [16] for Geometric Subduction use [32], for site class BC rock and global source subduction use [33], and with variable VS30 use [34].

Table 2. Paper related to attenuation of the city of Yogyakarta and its surroundings

Attenuation	2007	2010	2011	2013
(Ambraseys et al., 2005)	√		√	
(Campbell & Bozorgnia, 2003)	√		√	
(David M Boore et al., 1997)		√		
(Zhao et al., 2006)				√
(Atkinson & Boore, 2003)				√
(Youngs et al., 1997)				√
(Takahashi et al., 2000)		√		

4. Result and Discussion

4.1 Comparison User-Supplied Seismic Hazard Maps between HAZUS and Research

1.1. From the results of the comparison between the 2017 (Figure 2) and 2010 (Figure 3) from Indonesian Earthquake Zone Maps, compared the PGA values between the same location, namely Sedayu Permai Housing in Bantul District, Yogyakarta Province, which have coordinate location in

Latitude: -7.827° S Longitude: 110.256° E (Figure 4). Result of comparison between 2010 and 2017 Earthquake Zone Maps in (Figure 5)

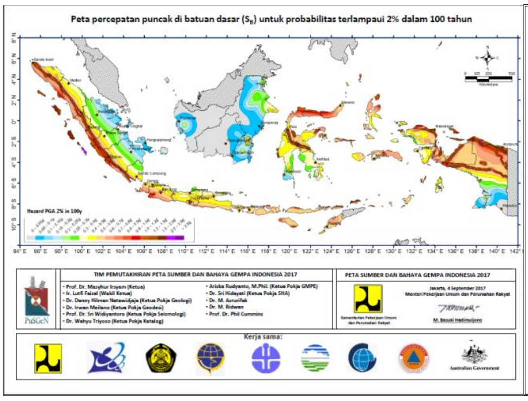


Figure 2. Seismic Zone Map Indonesia [16]

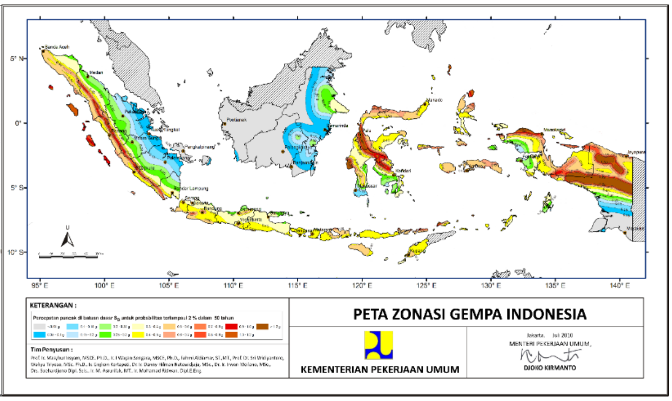


Figure 3. Seismic Zone Map Indonesia [35]

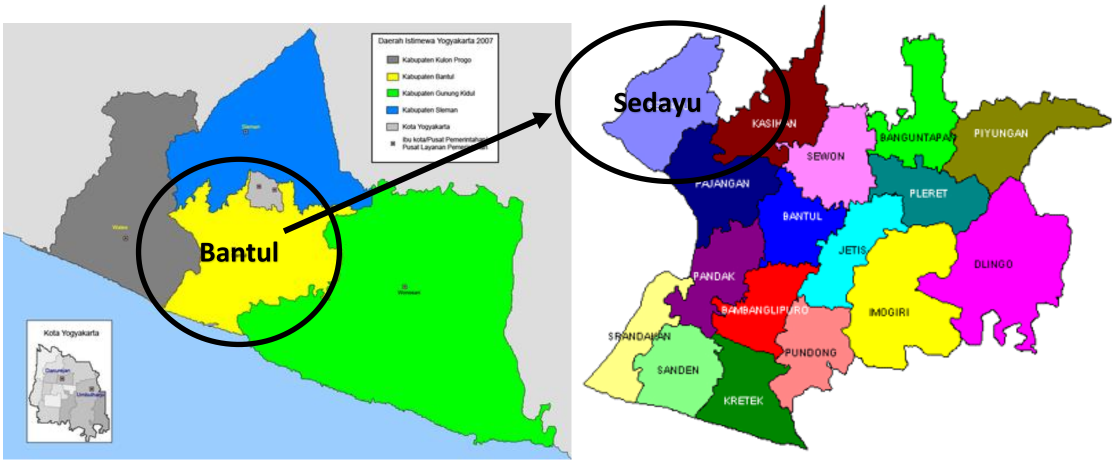
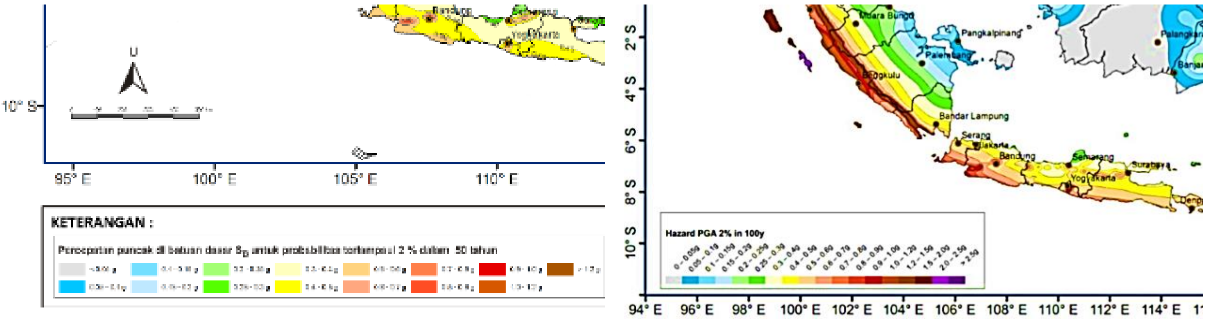


Figure 4. Sedayu Sub district, Bantul District [36-37]



(2010) (2017)

Figure 5. Comparison of seismic zone map of Sedayu Permai [16,35]

Based on Figure 5, PGA based on Earthquake Zone Map 2010 categorized in PGA 0,4 – 0,5 g and then in 2017 categorized in PGA 0,5 – 0,6 g. From there Indonesian Earthquake Zone Maps PGA based on HAZUS in UBC Zone Map (Figure 1), are categorized in Zone 4 = 0.4 g.

4.2 Standard Shape of Response Spectra from Research Result

PGA for obtained from The Ministry of Public Works-Centre for Research and Development of Housing and Settlements (PU PUSKIM) Indonesia website based on Seismic Zone Map 2010 (Figure 6) from the Sedayu Permai location in 7.826° S, 110.256° E (Table 3).

The graph between T (Period) and S_A (Spectral Acceleration, obtained from The Ministry of Public Works-Center for Research and Development of Housing and Settlements (PU PUSKIM) Indonesia website from Sedayu Permai, with hard soil can be shown in Table 4 and Figure 6..

Table 3. The Calculation Results 1

Variable	Value
PGA (g)	0.437
SDS (g)	0.657
SD1 (g)	0.36

Table 4. The Calculation Results 2

T (detik)	SA (g)
0	0.263
T0	0.657
TS	0.657
TS+0	0.555
TS+1	0.218
TS+2	0.136
TS+3	0.099
4	0.09

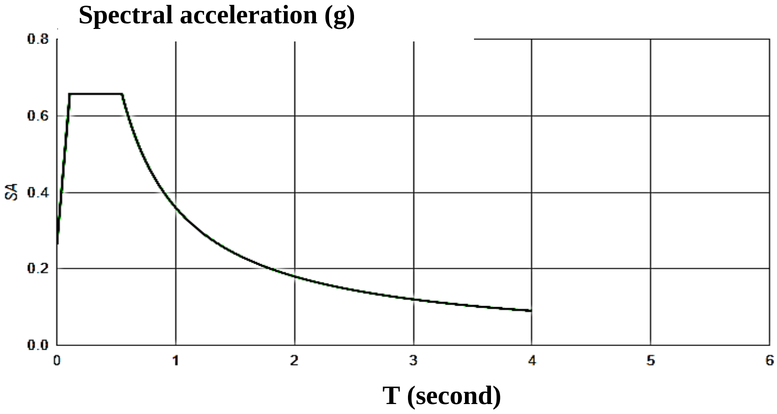


Figure 6. Spectrum Response Design for all model building type of research

From Table 3, can be explained that value of PGA which compare between Earthquake Zone Map (2010 in Chapter 4.1 is 0.4 – 0.5 g, and from the result from PGA has same value there is 0,437 g (between 0.4-0.5 g).

4.3 Comparison Attenuation of ground shaking between HAZUS and research

Whereas the tectonic setting in Yogyakarta Earthquake is that of significant subduction of the Indo-Australian plate under Eurasia, with the region affected being on the Sunda micro-plate, fault plane solutions indicated a left-lateral strike-slip mechanism is trending North East (NE) – South West (SW).

In Hazus, attenuation equation which have same fault strike and mechanism with Yogyakarta Earthquake there are: NGA - [26], NGA - [27], NGA - [26]. There is the newest attenuation from Boore, Chiou and Campbell in 2008, difference with GMPE for Indonesia Earthquake Zone Map still using Indonesia same attenuation but an old one.

5. Conclusion

From the 3 methods of finding Ground Motion Prediction Equation (GMPE) based on the HAZUS method, all methods are suitable for used in Sedayu Permai Housing, but the suitable using the latest attenuation equation from [25] for the BC class site rock and global source subduction use. In HAZUS method for estimate seismic hazards which include earthquake sources and ground motion prediction. Therefore, is needed necessary from an experts' judgment to evaluate because different mechanism of earthquake for Indonesian seismic hazard.

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