Analysis of Bedrock Synthetic Ground Motion on Bandung City using PSHA Method

Arifan Jaya Syahbana[1], Anggun Mayang Sari[2], Eko Soebowo[2], Masyhur Irsyam[3], Muhammad Asrurifak[4], Hendriyawan[5]

[1] *Student of Doctoral Program of Civil Engineering, FTSL ITB, Bandung, Indonesia*
[2] *Researchers LIPI, Bandung, Indonesia*
[3] *Professor of Civil Engineering, FTSL ITB, Bandung, Indonesia*
[4] *Researcher of PPMB ITB, Bandung, Indonesia*
[5] *Marine Engineering Lecturer, FTSL ITB, Bandung, Indonesia*
E-mail: arifanjaya@s.itb.ac.id

ABSTRACT: It is a necessity to calculate ground motion in large and dense urban areas such as Bandung City. In order to calculate the threat of earthquake hazard and risk both primary analysis (for soil or structural dynamic stability) and secondary analysis (for liquefaction) requires bedrock ground motion. The synthetic ground motion could be an alternative method if the recording data is not attained yet. This study used Probabilistic Seismic Hazard Analysis (PSHA) method to generate the synthetic ground motion on the bedrock. This study used earthquake sources in the radius area of 500 km from the survey location, using the latest earthquake data in order to obtain results closer to real condition. These ground motions were useful for identifying site soil response and mitigation. The results of peak ground acceleration at the bedrock are 0,502g; 0,505g; 0,510g and 0,539g for BH-1, BH-2, BH-6, and BH-7 site, which is similar to the analysis result of Indonesian Earthquake Source and Hazard Map 2017 at 2475 years return period.
Keywords: bedrock synthetic ground motion, PSHA, Bandung City

1. INTRODUCTION

1.1 Hazard Analysis

Analysis of ground motion for large and dense urban areas such as Bandung City is very needed. The purpose of calculating the earthquake hazard is to determine the primary hazard (earthquake shock) and secondary hazards (phenomenon). In seismic analysis for structural building, sometimes ground motion is required in the dynamic analysis (Argyroudis & Pitilakis, 2012; Azzam, 2014; Houshmandan, Rasouli, & Hajiamiri, 2014; Sugianti, Sari, & Syahbana, 2015; Syahbana & Sugianti, 2013; Xiaodong, Weiyuan, & Ruoqiong, 2001). Problems arise if there is no data recorded ground motion at that location. Thus, an approach is needed to obtain the ground motion, which is referred to synthetics ground motion.

In this study, earthquake hazard in bedrock will be analyzed using PSHA approach. It is compulsory to gain earthquake data with a radius of 500 km from the study location to get spectral curves from various sources (Uniform Hazard Spectra/UHS). The next analysis is deaggregation to determine the dominant earthquake source to obtain the response spectra. The next step is generating spectral matching from UHS and RS, and the last is running spectral matching using ground motion database. The result is synthetics ground motion.

1.2 EZ-FRISK

EZ-FRISK ™ is one of earthquake analysis software that contains several key capabilities which are Seismic Hazard Analysis, Spectral Matching, and Site Response Analysis. This capability allows various seismic hazard issues to be solved with direct input specifications using a graphical user interface. EZ-FRISK ™ is designed to be a user-friendly tool for beginners who often interact with seismic issues. This allows seismic risk analysts focused on identifying key inputs and making decisions that affect earthquake hazard evaluation, rather than in routine preparing input files, running command line programs, and plotting out the calculated results. EZ-FRISK ™ helps analysts make a better risk mitigation planning and decisions in dealing with earthquake threats (Risk Engineering, 2011).

2. PROBABILISTIC SEISMIC HAZARD ANALYSIS (PSHA)

2.1 Seismic Sources

Seismic sources used in this study are included all mechanism (shallow crustal and megathrust) within 500 km from studied location (Table 1 and Table 2). These sources are obtained from many catalogue (USGS, Engdahl, BMKG, and PusGen).

Table 1. Seismic Source for Megathrust

Structure	Segment	L (km)	W (km)	M PSHA	b-val	a-val
Sumatran Megathrust	Selat Sunda	290	100	8.7	1.15	5.99
Sunda Megathrust	West-Central Java'	700	150	8.7	1.08	5.55
Sunda Megathrust	East Java	280	150	8.7	1.08	5.63

Table 2. Seismic Source for Shallow Crustal

Segment	Type	Dip	L (km)	W (km)	M Max
Kumering-North	SS	~90	111	20	7.5
Kumering-South	SS	~90	60	20	7.1
Semangko Barat-A	SS	~90	90	20	7.4
Semangko Barat-B	SS	~90	80	20	7.3
Semangko Timur-A	SS	~90	12	20	6.5
Semangko Timur-B	SS	~90	35	20	6.9
Semangko Graben	Normal	60	50	20	6.5
Ujung Kulon A	SS	~90	80	20	7.3
Ujung Kulon B	SS	~90	150	20	7.6
Cimandiri	R	E-W	23	23	6.7
Nyalindung-Cibeber	R		30	15	6.5
Rajamandala	SS		45	22.5	6.6

Lembang	SS	E-W	29.5	29.5	6.8
Subang	R	NW	33	16.5	6.6
Cirebon-1	R	NW	15	7.5	6.5
Cirebon--2	R	NW	18	9	6.5
Karang Malang	R	EW	22	22	6.7
Brebes	R		22	11	6.5
Tegal	R	ENE	15	15	6.5
Pekalongan	R	NE	16	16	6.6
Weleri	R		17	17	6.6
Semarang	R	EW	34	17	6.6
Rawapening	R	NW	18	9	6.5
Demak	R	EW	31	15.5	6.6
Purwodadi	R	EW	38	19	6.7
Cepu	R	ESE	100	50	7.1

2.2 Attenuation

Attenuation used to calculate fault/shallow crustal mechanism are Bore-Atkinson (2008) NGA USGS 2008, Campbell-Bozorgnia (2008) NGA USGS 2008 and Chiou-Youngs (2007) NGA USGS 2008. Then, atttenuation for subduction mechanism is Zao et all (2006) USGS 2008, Atkinson-Bore (2003) Worldwide Subduction USGS 2008 and Young (1997) Subduction Rock All.

2.3 Site Location

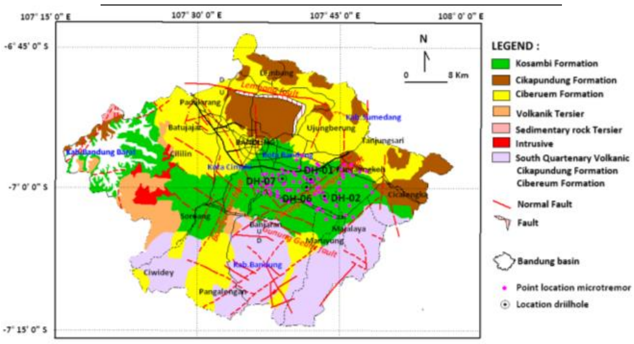
Bandung basin plains represent depression in West Java that shows the basin between the mountains (van Bemmelen, 1949 in Dam, 1994). The basin is surrounded by Quarter volcano cones and lava domes that are characterized by active volcanic activity. Basin Bandung has a length of approximately 60 km starting from Padalarang-Nagrek and width 40 km from Lembang-south Soreang. This height is between 650 m to 2200 m. The Bandung Basin is composed of lake sediments, lake fans, swamps, alluvial fans, floodplains, paleosoils of the Quaternary, in the middle of the basin there are four runways of lake clay with layers of volcaniclastic and fluvial facies (Dam, 1994). These sediment conditions are soft and consolidated. The Bandung basin plain is a historical record of environmental change as it grows in continuous physical changes such as changes in river flow, flooding, degradation and neotectonics on different time scales at the time to illustrate some types of sedimentary facies, where the condition of geological structures is a determinant of the sedimentation process (Dam, 1994). This process is characterized by the looping of the silt-sand unit (flood plains), the clay of lakes and gravel (alluvial fans) with varying thickness and geometric shapes in several locations mutually paying and slightly decreasing and rising and cutting.

Based on the geological history of the Bandung Basin area in the Quaternary (Dam, 1994), there are several volcanic fans sourced from Mount Malabar and Wayang Mountain Complex in the south and Manglayang Mountain in the north, there are also 4 phases of material that fill the ancient lake basin of Bandung. Formation Cibeureum lithology compilers of volcanic fans with lithology tufa sand, lapili, breccia, lava and aglomerate (Qyu) and the results of old volcano collapse (Qc) mainly found in the north and south (Silitonga, 1973). Kosambi Formation proposed by Koesoemadinata & Hartono (1981) to substitute the name of the Lake Deposit used by Silitonga (1973). Kosambi Formation is also used for the name of Lake Deposits used by Alzwar, Akbar, & Bachri (1992) and Sudjatmiko (1972). The distribution of this formation on the surface is in the middle. Its lithology consists mainly of claystone, limestone, and unbranched sandstone with Holocene age. This formation has a fascinating relationship with the upper Cibeureum Formation. Cikapundung Formation is the oldest rock unit exposed in the study area (Koesoemadinata & Hartono, 1981), and consists of a conglomerate and compact breccia, tuff, and andesite lava. The age of this formation is thought to be early Plistocene. The compactness of the lithology of this formation can be used as one of the distinctions with Cibeureum Formation, as well as the basis for determining this formation as bedrock in this area. According to (Silitonga, 1973), this formation is equivalent to Qvu. In addition to this formation, based on its lithological properties, Qvl, Qvb, Qob, and Qyl can be included as bedrock. Other units that form the bedrock are Quaternary volcanic rocks (except Cibeureum Formation and Cikapundung Formation), Tertiary volcanic rocks, Tertiary sedimentary rocks, and breakthrough rocks encompassed in geologic maps composed by Alzwar et al. (1992) and Sudjatmiko (1972). Based on the gravity data on the basin of Bandung reflect basement / basement configuration, it is seen that graben structure pattern of low and high that describe has happened deformation process which is controlled by the appearance of structure of alignment of northwest trending structure -southeast and northeast-southwest. Lower Zone such as in Dayeukolot, Cimahi, Rancaekeh and altitude in Gedebage, Banjaran, Cililin. Water drilling data and geotechnics drilling by Soebowo et al. (2016) and Tohari et al. (2015) show that bedrocks are found at depths -50 to -80 m in the eastern part of Gedebage, apparently in some locations may be more than 90 meters. The seismicity recorded in the Bandung Basin in 2011 by Sulaeman & Hidayati (2011) is 3.4 SR. In addition, the history of seismicity in the Bandung Basin was also observed in 1999, 2000, 2003, 2004, 2005 (Marjiyono, Soehaimi, & Kamawan, 2008).

The study area consists of four locations in Bandung area. This location is a point that belongs to the eastern area of Bandung and still lies in the basin of Bandung. The point coordinates to be reviewed can be observed in Table 3 and can be seen in Figure 1.

Table 3. Coordinates of Site Location

Location	Latitude	Longitude
BH-1	-6.981917	107.700945
BH-2	-7.01091	107.725492
BH-6	-6.995883	107.693052
BH-7	-6.981313	107.65068



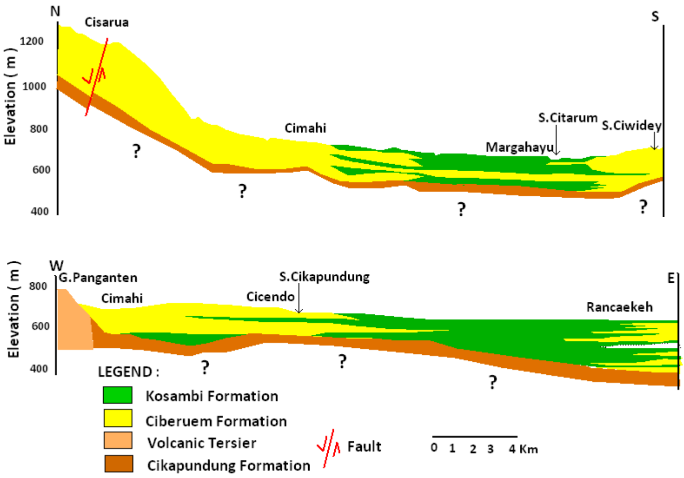


Figure 1. Site Location and schematic cross section geological sub surface Bandung basin (modified from Hutasoit (2009)).

3. DEAGGREGATION

Deagregation is the process of determining magnitude (M) and distance (R) which is dominantly based on the result of total probability which gives the biggest hazard contribution to the location reviewed in the time of earthquake request and period of building structure. The distance and magnitude are determined based on the relationship between magnitude, distance and rate (incidence/year over the acceleration being reviewed) to then searched for emphasis on the 3D deaggregation curve (Asrurifak, 2010; Irsyam, 2012). The equations used can be seen in Equations 1 and 2 (Sunardi, 2015).

$$M_{dominant} = \frac{\sum M_i \; x \; (\text{contribution of event/year})}{\sum(\text{contribution of event/year})} \qquad (1)$$

$$R_{dominant} = \frac{\sum R_i \; x \; (\text{contribution of event/year})}{\sum(\text{contribution of event/year})} \qquad (2)$$

The pair of one magnitude (M) and the distance from the site to the dominant source (R) and the hazard due to the earthquake can be expressed in one function. This concept obtains on seismic deaggregation (McGuire, 2001). Deaggregation can provide an overview of earthquake magnitude and distance for a particular earthquake source, which is likely to have a major effect on the site. One deaggregation purpose is in the dynamic analysis of a building with a large number of floors. In the dynamic analysis of such high-rise buildings, it is not possible to use PSHA's ground motion input, for which the PSHA result mechanism is a combination of various earthquakes mechanism. For that, it is needed separation of earthquakes that represent each mechanism. Referring to the Earthquake Indonesian National Standard 2012, it is required to simulate the earthquake at least 5 pieces of ground motion input representing all existing mechanisms (Anonim, 2012).

In deaggregation analysis, the selected point is PGA period (period close to 0 sec) and return period of 2475 years with damping 5%. Analysis result using Ez Frisk software can be observed in Figure 2.

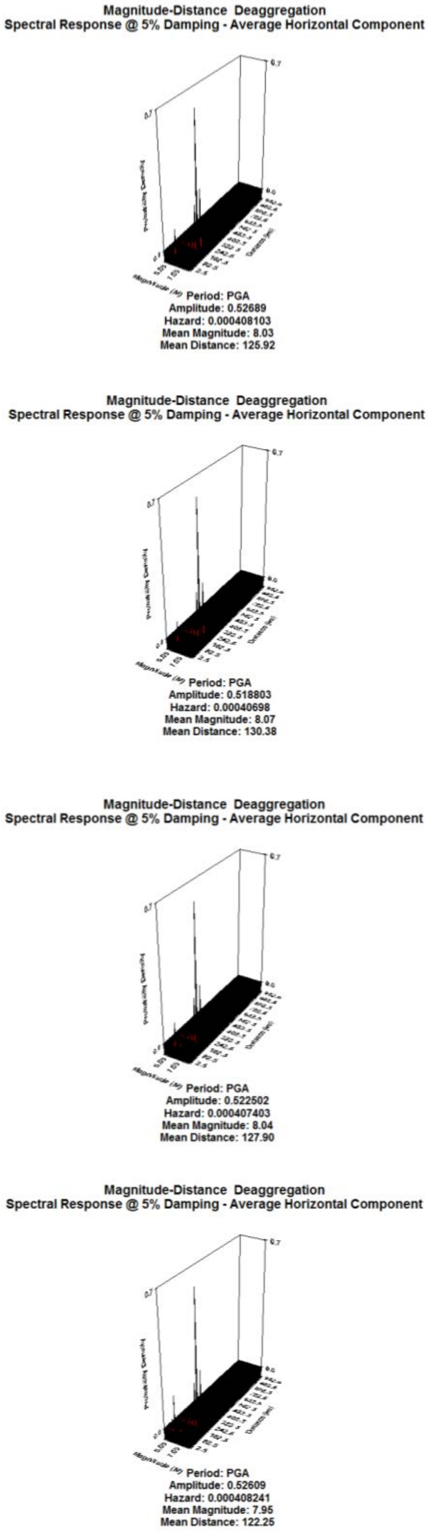


Figure 2. The result of deaggregation at BH-1, BH-2, BH-6 and BH-7 site.

Once the result of deaggregation at certain location obtained, then it is necessary to define what earthquake mechanisms affected the hazard predominantly. Here the mechanism could be determined by observing the graph relationship between hazard and PGA curved (often referred to as hazard curve). The function of this graph is to obtain earthquake spectra with modification of Uniform Hazard Curve. This graph of hazard and PGA relationships can be observed in Figure 3.

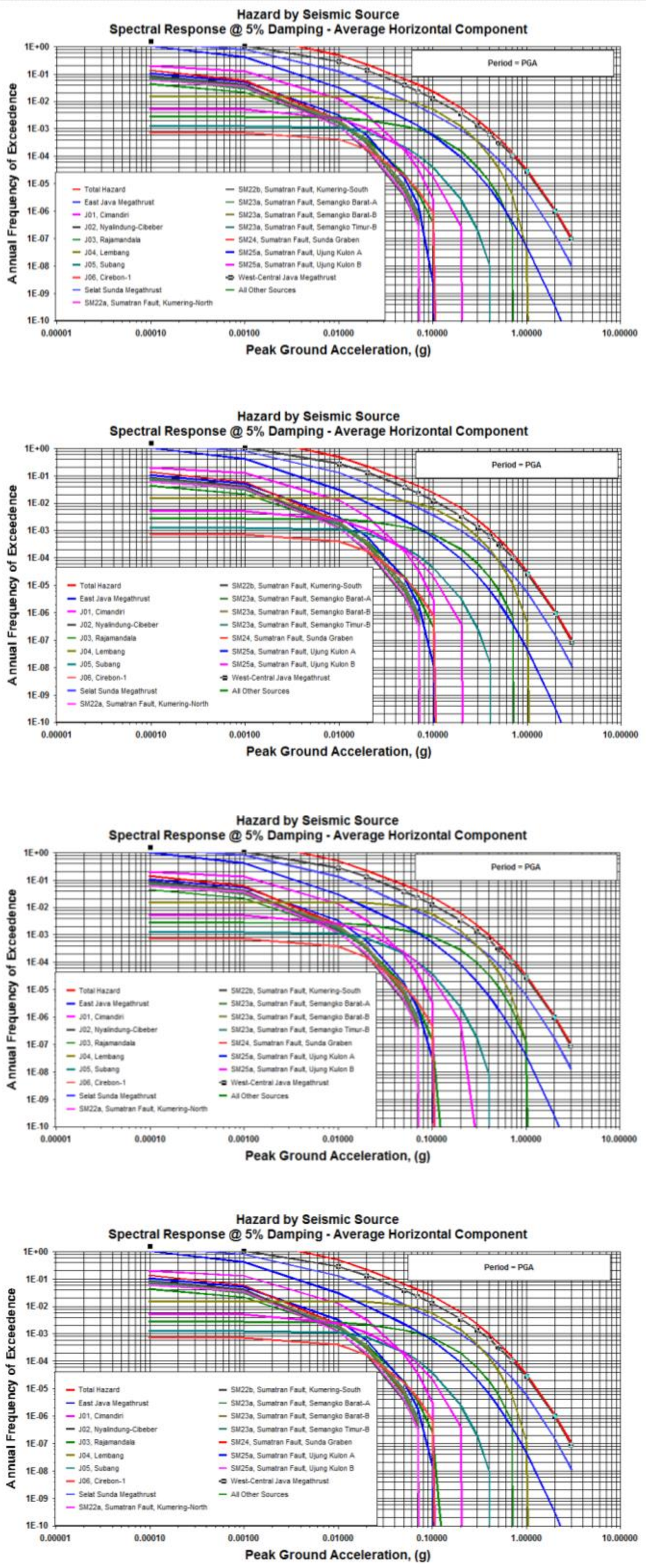


Figure 3. Hazard Curve of various earthquake sources at BH-1, BH-2, BH-6 and BH-7 site.

As shown in Figure 3 the dominant mechanisms obtained in the four review sites are Sunda Megathrust in the central-western part of Java based the PGA dan hazard result.

4. SPECTRAL MATCHING

4.1 Spectral Matching

Spectral matching is conducted to restrain the period that become concerned to be key of this process. In some work, period that become to be point of interest is structure period, where in some study there is PGA period. In this study, the period to be used is PGA.

As mentioned before, the reference is the hazard curve of the Uniform Hazard Spectra (involving all seismic mechanisms around the site), so that the deagregated (RS) spectral response follows the bonding point of the period by multiplying by a certain coefficient. This coefficient is then applied to the entire period. In this study, the RS was calculated based on the Young 1997 attenuation for the subduction mechanism. Spectral Matching results can be observed in Figure 4.

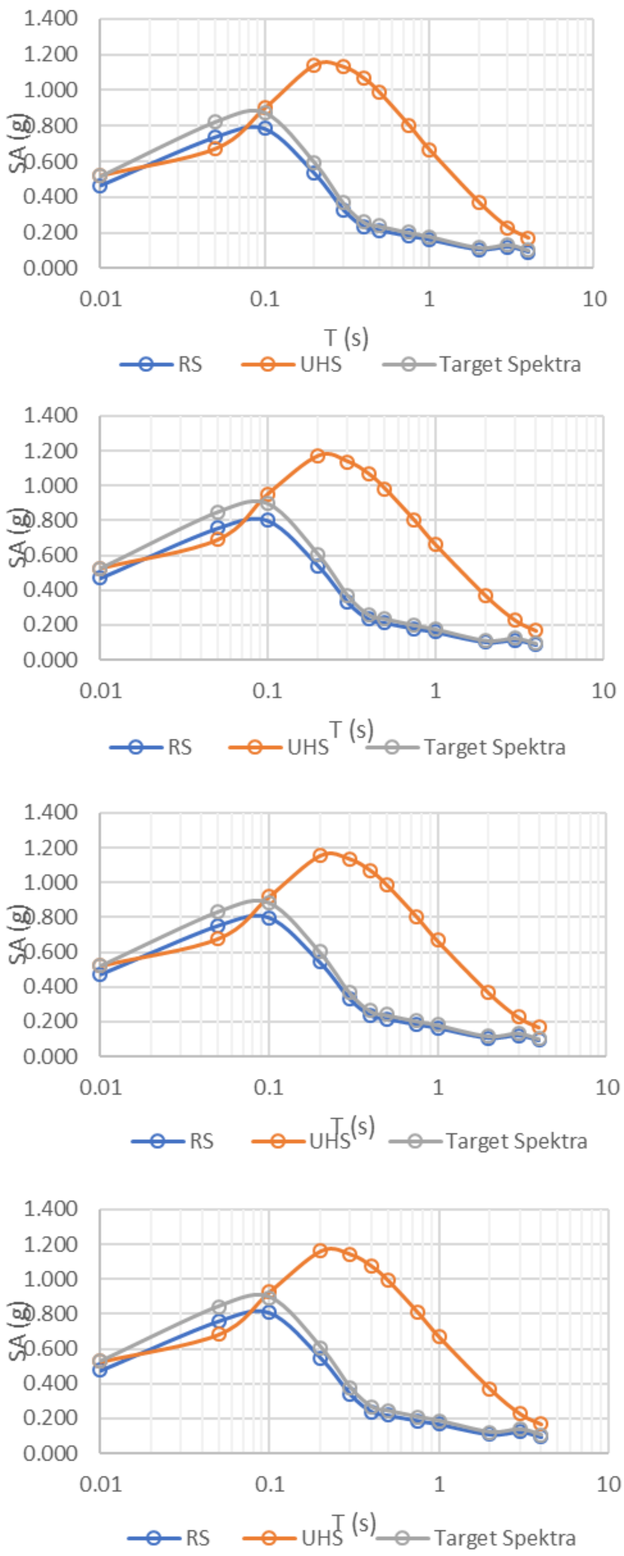


Figure 4. Spectral matching at at BH-1, BH-2, BH-6 and BH-7 site.

4.2 Ground Motion Selection

By comparing the spectral response to the existing ground motion data base, the results obtained as shown in Figure 5. The peak acceleration of the ground motion based on the ground motion synthetic formed is 0.502g; 0,505g; 0.510g and 0.539g for the location of BH-1, BH-2, BH-6 and BH-7 respectively.

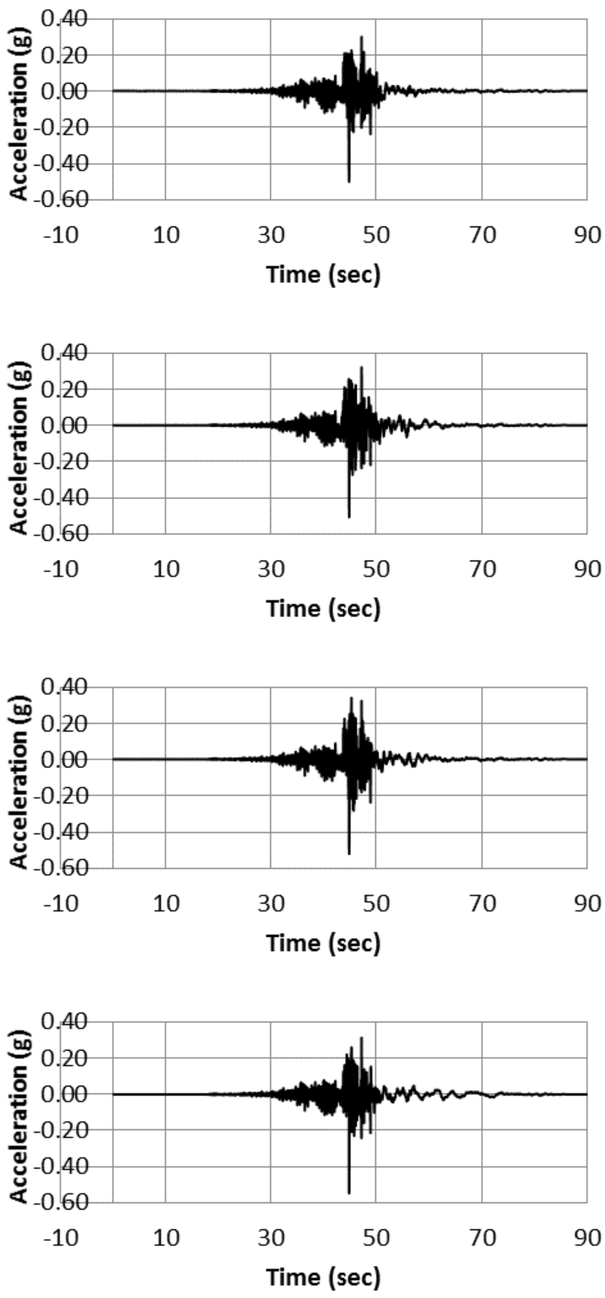


Figure 5. Ground motion at locations at BH-1, BH-2, BH-6 and BH-7 site.

The value of PGA produced in this study is valid compare to the result PusGen Research Team on Indonesia Earthquake Source and Hazard Book of 2017 for the area around Bandung City which is worth between 0,5-0,6g as presented in Figure 6. Thus, PGA value into the top of the spectra in each synthetic ground motion can be used as input on the analysis.

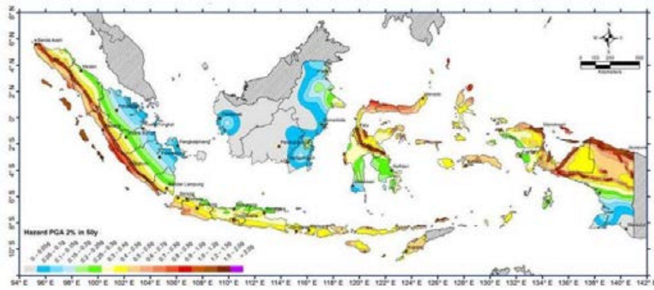


Figure 6. Peak acceleration (PGA) at 2475 year old basalt rock (2% exceeded in 50 years) from PusGen (2017)

5. CONCLUSION AND RECOMMENDATION

Based on this study, it can be concluded that the peak acceleration on bedrock based on synthetic ground motion on the return period 2475 years is 0.502g; 0,505g; 0.510g and 0.539g for the location of BH-1, BH-2, BH-6 and BH-7 sites. This is result has the same value with the Map of Earthquake Source and Hazard Indonesia in 2017 (PusGen, 2017) for the Bandung area during the PGA period. In addition, ground motion synthetic analysis is highly sensitive to 1) the result of deagregation which will affect the attenuation to be used in determining deaggregation spectral response and 2) adjustment of the ground motion database affected by the completeness of the database. The result of ground motion can be different between the researchers with each other depending on the data base owned.

In order to calculate ground motion on the surface and its effect on amplification in the Bandung Basin area, the basin effect should be taken into account

6. ACKNOWLEDGMENTS

The authors would like to thank the Indonesian Endowment Funds of Education (LPDP) for the scholarship being granted to carry out doctoral studies in ITB. Acknowledgments are also addressed to the LIPI research team of the Center for Geotechnology Research on data and cooperation in this paper. Last and not least, the authors say many thanks to the promoter for the science and guidance that has been given and to others who helped this project whom cannot be mentioned one by one.

7. REFERENCES

Alzwar, M., Akbar, N., & Bachri, S. (1992). Peta Geologi Lembar Garut dan Pameungpeuk, skala 1: 100.000. *Pusat Penelitian Dan Pengembangan Geologi, ESDM, Bandung*.

Anonim, A. (2012). SNI 1726:2012 Tata Cara Perencanaan Ketahanan Gempa untuk Struktur Bangunan Gedung dan Non Gedung, (1), 149.

Argyroudis, S. A., & Pitilakis, K. D. (2012). Seismic fragility curves of shallow tunnels in alluvial deposits. *Soil Dynamics and Earthquake Engineering*, *35*, 1–12.

Asrurifak, M. (2010). Peta Respon Spektra Indonesia Untuk Perencanaan Struktur Bangunan Tahan Gempa Dengan Model Sumber Gempa Tiga Dimensi Dalam Analisis Probabilitas. *Disertasi Doktor Teknik Sipil ITB, Indonesia*.

Azzam, W. R. (2014). Seismic Response of bucket Foundation and structure under earthquake loading. *Electronic Journal of Geotechnical Engineering*, *19*, 1477–1489.

Dam, M. A. C. (1994). The Late Quaternary Evolution of the Bandung Basin, West-Java, Indonesia. *Thesis Vrije Universiteit, Amsterdam*, 252.

Houshmandan, H., Rasouli, R., & Hajiamiri, M. (2014). The Effect of Near Fault and Far Fault Earthquake on Dynamic Analysis of Concrete Face Rockfill Dam with Case Study on the Neka, Gelevard CFRD. *Journal of American Science*, *10*(1s).

Hutasoit, L. M. (2009). Kondisi Permukaan Air Tanah dengan dan tanpa peresapan buatan di daerah Bandung: Hasil Simulasi Numerik. *Indonesian Journal on Geoscience*, *4*(3), 177–188.

Irsyam, M. (2012). Pengantar Dinamika Tanah dan Rekayasa Gempa. *Catatan Kuliah Jurusan Teknik Sipil ITB*.

Koesoemadinata, R. P., & Hartono, D. (1981). Stratigrafi dan sedimentasi daerah Bandung. *PIT X Ikatan Ahli Geologi Indonesia, Bandung*.

Marjiyono, M., Soehaimi, A., & Kamawan, K. (2008). IDENTIFIKASI SESAR AKTIF DAERAH CEKUNGAN BANDUNG DENGAN DATA CITRA LANDSAT DAN KEGEMPAAN. *Jurnal Geologi Dan Sumberdaya Mineral*, *18*(2), 81–88.

McGuire, R. K. (2001). Deterministic vs. probabilistic earthquake hazards and risks. *Soil Dynamics and Earthquake Engineering*, *21*(2001), 8.

PusGen. (2017). *Peta Sumber dan Bahaya Gempa Indonesia Tahun 2017* (1st ed.). Bandung: Puslitbang Perumahan dan Pemukiman.

Risk Engineering, I. (2011). EZ-FRISK.

Silitonga, P. H. (1973). Peta Geologi Lembar Bandung, skala 1: 100.000. *Bandung: Pusat Penelitian Dan Pengembangan Geologi*.

Soebowo, E., Tohari, A., Wibowo, S., Sugianti, K., Sari, A. M., Satriyo, N. A., … Lestiana, H. (2016). *Kajian Ancaman Seismik dan Gerakan Tanah di Wilayah Kawasan Strategis Cekungan Bandung*. Bandung.

Sudjatmiko. (1972). skala 1: 100.000 (Pusat Penelitian dan Pengembangan Geologi, 1972). *Google Scholar*.

Sugianti, K., Sari, A. M., & Syahbana, A. J. (2015). DMT method approach for liquefaction Hazard Vulnerability Mapping in Bantul Regency, Yogyakarta Province, Indonesia. *Indonesian Journal on Geoscience*, *2*(1). https://doi.org/10.17014/ijog.2.1.53-61

Sulaeman, C., & Hidayati, S. (2011). Gempa Bumi Bandung 22 Juli 2011. *Jurnal Lingkungan Dan Bencana Geologi*, *2*(3), 185–190.

Sunardi, B. (2015). Percepatan Tanah Sintetis Kota Yogyakarta Berdasarkan Deagregasi Bahaya Gempa. *Journal of Environment and Geological Hazards*, *Vol. 6 No.*(Desember 2015), 211–228.

Syahbana, A. J., & Sugianti, K. (2013). Pemodelan 2D perubahan tekanan air pori hubungannya dengan Likuifaksi: Studi kasus Kabupaten Bantul, Daerah Istimewa Yogyakarta. *Jurnal Lingkungan Dan Bencana Geologi*, *4*(3), 163–177.

Tohari, A., Soebowo, E., Wibowo, S., Syahbana, A. J., Sari, A. M., Sugianti, K., … Lestiana, H. (2015). *Kajian Ancaman Seismik dan Gerakan Tanah di Wilayah Kawasan Strategis Cekungan Bandung*. Bandung.

Xiaodong, K., Weiyuan, Z., & Ruoqiong, Y. (2001). STABILITY ANALYSIS ON THE HIGH SLOPES OF THREE-GORGES SHIPLOCK USING FLAC-3D [J]. *Chinese Journal of Rock Mechanics and Engineering*, *1*, 6–10.