The Sensitivity of Attenuation Impact to Bedrock PGA Based on PSHA Analysis, Case Study: Yogyakarta Special Region, Indonesia

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Abstract. Special Region of Yogyakarta is one of the big cities in Indonesia which has important meaning from the political, social, economic and cultural aspect. This area is located in a high earthquake hazard zone based on the 2017 Earthquake Hazard Map. This location also mentioned has accelerated bedrock acceleration up to 0.6g. In this study, a re-analysis of PSHA will be carried out using the OpenQuake software with the GEM database and the latest attenuation to see the number of acceleration differences generated in the bedrock. Simulation is done by making two logic tree attenuation scenarios, later called the Pusgen scenario (1) and the Cummin's scenario (2). The result of this study is the first scenario will result in an acceleration greater than the second scenario. Bedrock PGA based on the Pusgen scenario range from 0.431-0.720g on another hand Cummin's scenarios range from 0.405 to 0.709g.

Keywords: Earthquake Hazard, Attenuation, PGA, Openquake

1 Introduction

The Special Region of Yogyakarta is one of the provinces in Java that has great potential for geological disasters. This is due to the presence of Mount Merapi in the north, Subduction Zone in the south and Opak Fault in the area. A history of records of earthquakes that damaged the Yogyakarta several times such as on January 4, 1840; October 20, 1859; June 10, 1867; March 28, 1875, July 23, 1943; October 12, 1957; March 14, 1981, and the last one on May 27, 2006 (Mw 6.2) (**Figure 1b**). In terms of civil engineering, one of the main concerns is the influence of seismicity in the spatial development plan, especially infrastructure. Appropriate seismic analysis is obviously needed on this matter. Thus, in this study will be a lot of terms related to PSHA and PGA. PSHA (Probabilistic Seismic Hazard Analysis) is a method of seismic analysis that involving 3 probability, i.e magnitude, distance and exceeded acceleration [1], later will be further explained in the next chapter. PGA (Peak Ground Acceleration) itself is mean acceleration representing the maximum response of degree of freedom at a period near to 0 seconds and always obtained by attenuation equation [2–4]. Some research that has been done in the research area is the analysis of the focal mechanism by considering the source of

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subduction in the southern part of Java [5], synthetic ground motion [6] and making PGA maps in four major cities in Java use EzFrisk [7]. In this paper, a probabilistic analysis of seismicity (PSHA) will be carried out by considering several earthquake sources in Indonesia (fault, background and subduction) and attenuation logic trees which are supposed to contribute to PGA in bedrock and partially on the surface. The data used is a GEM database and being processed using OpenQuake software. GEM (Global Earthquake Model) is one of non profit organization that specialized in earthquake analysis included hazard and risk around the world. It consists of many earthquake expertise from a different country, like Costa Rica, India, Italy, Columbia and so on [8].

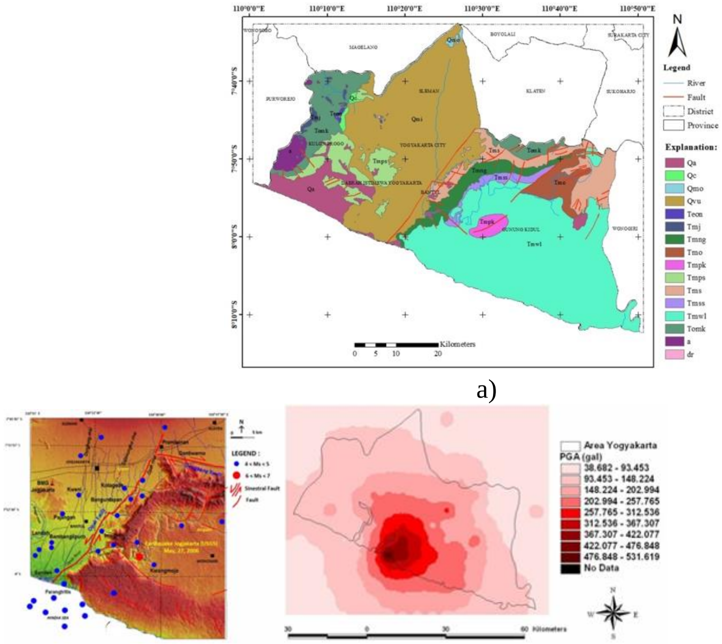
1.1 Research area

The Special Province of Yogyakarta is geographically located at 7 ° 33'-8 ° 15 'LS and 110 ° 5'-110 ° 50' BT. This province has an area of 3,185.81 km^2 or 0.17% of the total area of Indonesia. Based on the geology physiography, Special Region of Yogyakarta is a depression which is bounded by the Quaternary-aged Merapi Mountain in the north, the Southern Mountains in the east and the Kulon Progo Mountains in the west, where these mountain rocks are Tertiary aged and also surrounded by the Indian Ocean in the south [9].

Based on the geological map of Yogyakarta sheet [10] and the Surakarta and Giritontro sheets [11] the oldest rock outcrops in the Southern Mountains and Kulon Progo are the Kebo-Butak Formation of Oligocene to Early Miocene consisting of ancient volcanic products andesitic breccia, tuff, lapilli tuff, agglomerate, and collations of andesitic lava flows (**Figure 1a**). Furthermore, sediments are the Early Miocene Semirir Formation to Middle Miocene consisting of interbedded tuff-breccia, pumice breccia, dacite tuff, and andesite tuffs and tuffaceous claystone. The Nglanggran Formation is deposited incongruously above the Early Miocene Breezy Formation to the Middle Miocene which consists of volcanic breccia, flow breccia, agglomerate, lava, and tuff. Then precipitated Sambipitu Formation (tuff, shale, siltstone, sandstone and conglomerate). The marl and bedded limestone formation, the Wonosari Formation (reef limestone, calcarenite and tuffaceous calcarenite), the Miocene to Pliocene Sentolo Formation (limestone and marly sandstone). Above it is deposited unconformably with the Quaternary volcanic material of the Mount Merapi to date, the sedimentation process carried by rivers upstream on the slopes and dominates in the Yogyakarta Basin in the form of volcanic breccia, lava flows, tuff, tuffaceous sandstone and lahar. The iron-rich fine sand that has been carried by rivers to the sea is deposited by the wind as sand dunes along the southern coast of this basin. Furthermore, Alluvial Quaternary Old Deposits consist of gravel, sand, silt, and clay along larger streams and coastal plain.

The geological structure in the form of faults located between the Yogyakarta and Southern Mountains is known through gravity surveys [12]. The fracture in the form of a horizontal fault is known as the Opak fault that trails NE-SE with N 235° E / 80, where the western block is relatively down to the eastern block [10]. The width of the fault zone is around 2.5 km. In addition to the Opak fault, there is also another fault that is almost east-west direction to the Gantiwarno area. According to the interpretation of the Opak Fault is an active fault, but the type of movement is unknown [13]. The Opak Fault System has also been identified as a direction of fault trending north-south and northwest-southeast around the Opak Fault [14]. Based on geotechnical drilling data and geoelectric surveys, a fault system that is buried by volcanic deposits of Merapi which traverses north-south and east-west is also a continuation of the Opak Fault towards the Yogyakarta Basin [15].

The coastal areas of South Java are parts of the front arc which often experience earthquake shocks, earthquakes have more magnitude than Mw 4-6 and some Mw> 6 (**Figure 2**). The seismic record reveals the occurrence of the fault line structure that moves northeast-southwest and northwest-southeast. In general, indications of local mechanisms indicate the occurrence of fault zones and downward slide in the Opak Fault. The city of Yogyakarta has quite high and active seismicity and has surface peak acceleration whose values vary from 0.038 to 0.531 g [16].



a)

b) c)

Fig. 1. a) Geological Map of the Special Region of Yogyakarta and b) Map of earthquake distribution (c) tectonics of Jogjakarta (left) Map of peak ground accelerations in Yogyakarta (right).

1.2 PSHA

Probabilistic Seismic Hazard Analysis is a probabilistic approach in terms of seismicity consisting of probability magnitude, distance, and attenuation. This magnitude is based on history and the greatest potential that exists in the source structure of the earthquake. While distance contributes to the possibility of each coordinate in the earthquake source geometry structure to the point of review. While attenuation is influenced by the type of earthquake source that is present in the analysis. In general, the formula used in PSHA is as follows.

$$[Y > y*] = \iint P[Y > y* | m, r] f_M(m) f_R(r) dm. dr \quad (1)$$

With Y,y* = acceleration, exceeded acceleration; fM (m) and fR (r) is the probability density function magnitude and distance [1].

1.3 OpenQuake

OpenQuake is open-source and aims to calculate earthquake hazards and risks. For this study, the analysis was run on Linux at the Pusgen server. The advantage of this software is that the code repository is general and can be downloaded at http://github.com/gem/oq-engine. The execution of this tool uses the terminal on the operating system [8]. The analysis of this study uses one of Openquake's abilities, namely classical hazard analysis which refers to the previous researchers' proposals [17, 18] formulated by Field, Cornel and Jordan [19]. In this analysis, the output that can be produced is a hazard curve and a hazard map.

1.4 Data and Analysis

This study was conducted by collecting earthquake mainshock data in Indonesia from 1900 to 2016 and also taking into account the completeness time of each magnitude, this data was collected by GEM. The source of the earthquake that is divided into 3, namely fault, subduction which includes inter and intraplate and the last is the background. Background data contains a vast number of earthquake events with magnitude from 4.5-6.5 Mw for shallow depth (0-50km in-depth) and magnitude 4.5-7.8 Mw for deeper depth. Data on megathrust and fault earthquake sources can be seen in Table 1 and Table 2.

Table 1. Source of subduction earthquake.

Index	Structure name	Segment	L (km)	W (km)	Slip rate (cm/yr)	Mmax Geodesy
M1	Sumatran Megathrust	Aceh-Andaman	1300	200	4.0	9.2
M2	Sumatran Megathrust	Nias-Simelue	400	200	4.0	8.9
M3	Sumatran Megathrust	Batu	70	100	4.0	8.2
M4	Sumatran Megathrust	Mentawai-Siberut	200	200	4.0	8.7
M5	Sumatran Megathrust	Mentawai-Pagai	400	200	4.0	8.9
M4-5	Sumatran Megathrust	Mentawai	600	200	4.0	9.0
M3-4	Sumatran Megathrust	Batu Mentawai Siberut	270	200	4.0	8.8
M6	Sumatran Megathrust	Enggano	250	200	4.0	8.8
M7	Sunda-Strait Megathrust	Selat Sunda Banten (SSB)	280	200	4.0	8.8
M8	Java Megathrust	Jabar (JB)	320	200	4.0	8.8

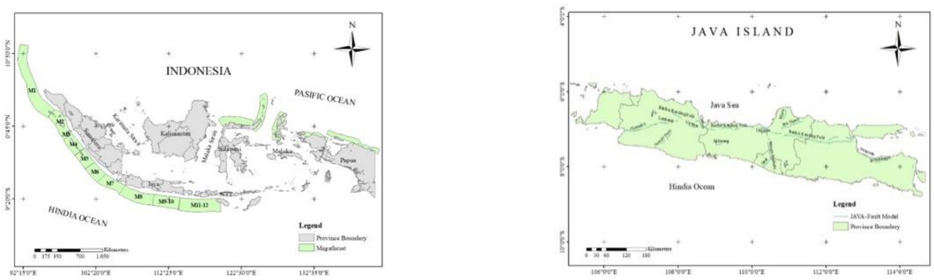
Index	Structure name	Segment	L (km)	W (km)	Slip rate (cm/yr)	Mmax Geodesy
M9	Java Megathrust	Jateng Jatim (JJ)	440	200	4.0	8.9
M6-7	Java Megathrust	Enggano-SS	530	200	4.0	9.0
M6-7-8	Java Megathrust	Enggano-SS-JJ	850	200	4.0	9.1
M7-8-9	Java Megathrust	SS-JB-JJ-JT	1040	200	4.0	9.2
M10	Java Megathrust	Bali	500	200	4.0	9.0
M11	Java Megathrust	NTB	400	200	4.0	8.9
M12	Java Megathrust	NTT	550	140	2.0	8.7
M13	Banda Megathrust	Laut Banda Selatan	640	170		7.4
M14	Banda Megathrust	Laut Banda Utara	830	130		7.9
M15	Northern Sulawesi Thrust	Northern Sulawesi	480	120		8.5
M16	Philippine Thrust	Philippine-Maluku	990	100		8.2

Table 2. Source of Fault Earthquake.

ID	Structure Name		Slip-Rate mm/yr	Sense Mechanism	Dip (km)	Top (km)	Bottom (km)	L (km)	Mmax (Mw)
	Main	Segment							
1	Cimandiri Fault	Cimandiri	0.55	Reverse-slip	45S	3	18	23	6.7
2	Cimandiri Fault	Nyalindung-Ciheber	0.4	Reverse-slip	45S	3	18	30	6.5
3	Cimandiri Fault	Rajamandala	0.1	Strike-slip	90	3	18	45	6.6
4	Lembang Fault	Lembang	2.0	Strike-slip	90	3	18	29.5	6.8
5	Baribis-Kendeng Fold-Thrust Zone	Subang	1	Reverse-slip	45S	3	18	33	6.5
6	Baribis-Kendeng Fold-Thrust Zone	Cirebon-1	0.1	Reverse-slip	45S	3	18	15	6.5
7	Baribis-Kendeng Fold-Thrust Zone	Cirebon-2	0.1	Reverse-slip	45S	3	18	IS	6.5
8	Baribis-Kendeng Fold-Thrust Zone	Karang Malang	0.1	Reverse-slip	45S	3	18	22	6.5
9	Baribis-Kendeng Fold-Thrust Zone	Brebes	0.1	Reverse-slip	45S	3	18	22	6.5

ID	Structure Name		Slip-Rate mm/yr	Sense Mechanism	Dip (km)	Top (km)	Bottom (km)	L (km)	Mmax (Mw)
	Main	Segment							
10	Baribis-Kendeng Fold-Thrust Zone	Tegal	0.1	Reverse-slip	45S	3	18	15	6.5
11	Baribis-Kendeng Fold-Thrust Zone	Pekalongan	0.1	Reverse-slip	45S	3	18	16	6.5
12	Baribis-Kendeng Fold-Thrust Zone	Weleri	0.1	Reverse-slip	45S	3	18	17	6.5
13	Baribis-Kendeng Fold-Thrust Zone	Semarang	0.1	Reverse-slip	45S	3	18	34	6.5
14	Baribis-Kendeng Fold-Thrust Zone	Rawa-Pening	0.1	Reverse-slip	45S	3	18	18	6.5
15	Baribis-Kendeng Fold-Thrust Zone	Demak	0.1	Reverse-slip	45S	3	18	31	6.5
16	Baribis-Kendeng Fold-Zone	Purwodadi	0.1	Reverse-slip	45S	3	18	38	6.5
17	Baribis-Kendeng Fold-Zone	Cepu	0.1	Reverse-slip	45S	3	18	100	63.0
18	Baribis-Kendeng Fold-Thrust Zone	Waru	0.05	Reverse-slip	45S	3	18	64	6.5
19	Baribis-Kendeng Fold-Thrust Zone	Surabaya	0.05	Reverse-slip	45S	3	18	25	6.5
20	Baribis-Kendeng Fold-Thrust Zone	Blumbang	0.05	Reverse-slip	45S	3	18	31	6.6
21	Ciremai		0.1	Strike-slip	90	3	18	20	6.5
22	Ajibarang		0.1	Strike-slip	90	3	18	20	6.5
23	Opak		0.75	Strike-slip	60E	3	18	45	6.6
24	Merapi-Merbabu		0.1	Strike-slip	90	3	IS	28	6.6
25	Pati Thrust		0.1	Strike-slip	90	3	18	69	6.5

The GMPE (Ground Motion Prediction Equation) scenario/attenuation used as a comparison is named (1) GMPE Pusgen, given this name to honor the analysis that the agency has done, and (2) Cummins GMPE, which is the name of a researcher from ANU who made this GMPE comparison. This scenario is arranged to see the sensitivities of GMPE used. **Figure 2** shows the data source that used.



a) b)

Fig. 2. The earthquake source for the analysis of this study consisted of (a) the source of the earthquake originating from fault (b) the megathrust earthquake source. The source of the earthquake background is in the OpenQuake input file which consists of shallow and deep sources [8].

The logic tree of GMPE can be described as follows: (1) for GMPE Pusgen in analyzing shallow earthquake sources (fault and background) are BooreEtAl 2014, Campbell-Bozorgnia2014 and ChiouYoungs2014; (2) interslab earthquake analysis (shallow subduction) are AbrahamsonEtAl2015Sinter, AtkinsonBoore2003Sinter and ZhaoEtAl2006Asc; and source analysis intraslab earthquake (deep subduction) are using AtkinsonBoore2003SSlab, YoungsEtAl1997SSlab, AbrahamsonEtAl2015-SSlab with each weight is 0.33; 0.33 and 0.34 respectively. While the GMPE Cummin logic tree is as follows: for shallow earthquake sources (fault and background) are BooreAtkinson2008 (0.2), CampbellBozorgnia2008 (0.2), ChiouYoungs2008 (0.2), BooreEtAl2014 (0.133), CampbellBozorgnia2014 (0.133), Chiou Youngs 2014 (0.134), interslab earthquake source (shallow subduction) with YoungsEtAl1997Sinter (0.15), AtkinsonBoore1995GSCBest (0.15), ZhaoEtAl2006Sinter (0.3), AbrahamsonEtAl-2015Sinter (0.4) and intraslab earthquake source (deep subduction) with GMPE YoungsEtAl1997-SSlab (0.33), AtkinsonBoore2003-SSlabNSHMP2008 (0.33) and AtkinsonBoore2003SSlabCascadiaNSHMP2008 (0.334). Those data and GMPE scenarios, then become input in OpenQuake software which is running in the Pusgen server.

2 Results

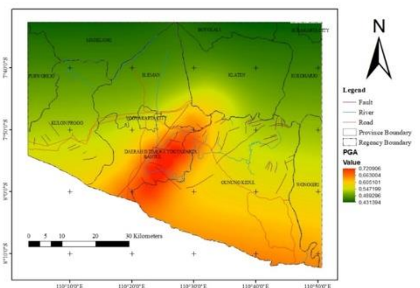
As a result of simulation using OpenQuake, PGA on bedrock is obtained. Sometimes, for many reasons, it is needed to obtain PGA on the surface, for example to the geotechnical field, structural analysis, etc. To analyze surface PGA, surface average N-SPT data as regulated in SNI 2012 is needed, both obtained by direct measurement or by approach. In this study, correlation data were used that connected the values of CPT (Cone Penetration Test) and CPT (electronic CPT) using the equation proposed by Kara and Gunduz (2010). Surface PGA is multiplication between factor PGA (FPGA) with PGA at bedrock. The calculation results can be seen in Table 3. Because of the dominant site class is SD and SE (due to the average N-SPT value of 30 m below ground level below 15), the maximum acceleration result on the surface will be a maximum difference of 10% from PGA on bedrock (**Figure 3 a and b**).

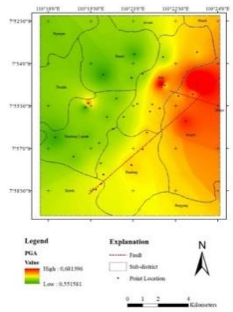
Table 3. Results of site class calculation recapitulation and bedrock-surface PGA.

No	Point	Location	Site Class	PGA bedrock	FPGA	PGA surface
1	BH01	Km 17, Patalan	SE	0.641	0.9	0.577
2	BH02	Masjid Pulokadang	SD	0.657	1	0.657
3	BH03	Pesantren	SD	0.681	1	0.681
4	BH04	Soronagan	SE	0.657	0.9	0.591
5	BH05	Gunungan, Sumbermulyo	SD	0.615	1	0.615
6	CPTu-01	Dukuh	SE	0.641	0.9	0.577
7	CPTu-02	Klesat	SE	0.669	0.9	0.602
8	CPTu-03	Semampir	SE	0.660	0.9	0.594
9	CPTu-04	Bakulan	SE	0.636	0.9	0.572

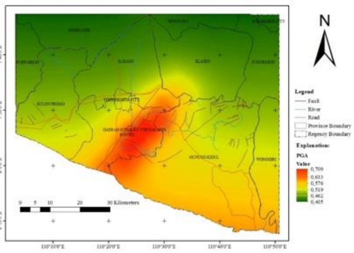
No	Point	Location	Site Class	PGA bedrock	FPGA	PGA surface
10	CPTu-05	Kembangsono	SE	0.665	0.9	0.599
11	CPTu-06	Karangtalun	SE	0.671	0.9	0.603
12	SD-01	Sawahan, Sri Hardono, Pundong, Bantul	SE	0.641	0.9	0.577
13	SD-02	Gerselo, Patalan, Jtis, Bantul	SE	0.645	0.9	0.581
14	SD-03	Pulau Kedung, Canden, Jetis, Bantul	SE	0.660	0.9	0.594
15	SD-04	Bangsan, Canden, Jetis, Bantul	SE	0.667	0.9	0.600
16	SD-05	Wonolopo, Canden, Jetis, Bantul	SE	0.669	0.9	0.602
17	SD-06	Gulon, Sri Hardono, Pundong, Bantul	SE	0.668	0.9	0.601
18	SD-07	Sorok, Kec Winongo, Sumber Mulyo	SE	0.633	0.9	0.570
19	SD-08	Cepoko, Sumber Mulyo, Bambanglipuro	SE	0.633	0.9	0.570
20	SD-09	Bakulan, Patalan, Jetis	SE	0.633	0.9	0.569
21	SD-10	Manding, Sabdodadi	SE	0.620	0.9	0.558
22	SD-11	Tulasan, Mulyodadi, Bambanglipuro	SE	0.632	0.9	0.569
23	SD-12	Kraton, Mulyodadi, Bambanglipuro	SE	0.630	0.9	0.567
24	SD-13	Jogodayoh, Sumbermulyo, Bambanglipuro	SE	0.617	0.9	0.555
25	SD-14	Tajeman, Palbapang, Bantul	SE	0.613	0.9	0.552
26	SD-15	Ngupit, Patalan, Jetis	SE	0.655	0.9	0.589
27	SD-16	Sawahan, Sumberagung,	SE	0.639	0.9	0.575
28	SD-17	Numpukan, Karangtengah, Imogiri	SE	0.702	0.9	0.632
29	SD-18	Sanggrahan, Sriharjo, Imogiri	SE	0.615	0.9	0.554
30	SD-19	Ngetal, Karangtalun, Imogiri	SE	0.675	0.9	0.608
31	SD-01M	Tilaman, Ds.Kedusan, Kel Wukirsari, Imogiri	SE	0.687	0.9	0.618
32	SD-02M	Turi,Sumberagung,Kec Jetis, Bantul	SE	0.645	0.9	0.580
33	SD-03M	SMPMuhamadiyah Jetis, Pulokadang,Canden	SE	0.660	0.9	0.594
34	SD-04M	Bangsan, Canden, Jetis, Bantul	SE	0.671	0.9	0.604
35	SD-05M	Candi, Srihardono, Pundong	SE	0.639	0.9	0.575
36	SD-06M	Weden, Panjangrejo, Pundong	SE	0.649	0.9	0.584
37	SD-07M	Klisat, Panjangrejo, Pundong	SE	0.669	0.9	0.602
38	SD-08M	Sorongan, Panjangrejo	SE	0.657	0.9	0.591
39	SD-09M	Semampir, Panjangrejo, Pundong	SE	0.656	0.9	0.590
40	SD-10M	RT 002 Semampir, Panjangrejo, Pundong	SE	0.659	0.9	0.593
41	SD-11M	Blawong 2, Trimulyo	SD	0.615	1	0.615

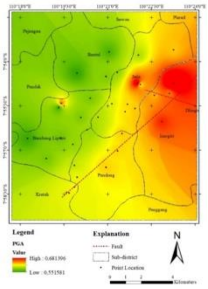
If there is a large amount of available data and present surface area entirely, micro zonation can be made smoothly. For the time being in this study, only 41 points were available, therefore the area that could be made micro zonation was covering the small area only. This can be seen in **Figures 3 (c) and (d)**.





a)





b) d)

Figure 3. Maximum acceleration (PGA) in the bedrock of Special Region of Yogyakarta (a) Logictree of GMPE Pusgen and (b) Logictree of GMPE Cummin. The results show that the PGA value of Pusgen is greater than the analysis of GMPE Cummin’s logic tree. PGA at surface based on site class (c) using Pusgen’s and (d) using Cummin’s the pattern of its looked like similar and value is slightly different.

The range of bedrock PGA values from this study is 0.431-0.720g for the Pusgen logic tree and 0.405 to 0.709g for the Cummin logic tree. When compared with the results of the previous study [7], this study resulted in higher baseline PGA values. From the Indonesian Earthquake Map, the value that appears is not exactly the same as this study, this is due to the consideration of other aspects taken by the competent and interested parties in this study. Thus, planning for infrastructure development that considers the seismic aspects of its design can refer to the result analysis of this study.

3 Conclusion

Based on this study, conclusions can be taken as follows. Acceleration in bedrock using the Pusgen attenuation scenario produces a greater value, which is in the range of 0.431-0.720g on another hand Cummin's scenarios range from 0.405 to 0.709g. Furthermore, with the surface conditions that enter the SD-SE site class, the surface PGA values are slightly different from those in the bedrock. Thus, the results of the analysis on the 2017 Indonesian Earthquake map are more conservative, with other words safer. The differences that exist with the results of the Indonesian Earthquake map are suspected because the taking of the range of values is not only due to technical aspects, but also involves political, economic and social aspects.

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