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Seismic hazard analyses for North Java Offshore Indonesia using ISO 19901-2:2004

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Abstract. Most offshore platforms in Indonesia use API RP 2A WSD as a guideline for designing earthquake-resistance offshore structures. However, this guideline does not explicitly state the return periods and the procedures for developing the designed response spectrum for used in seismic design. The procedures are described in more detail in ISO 19901-2 which stated explicitly requirement design parameter of 1.0s oscillator period and for a 0.2s oscillator period for a 1000-years return period of the earthquake. The paper presented a development of seismic hazard maps for 1.000 years return period for North Java Offshore Indonesia. The seismic hazard maps were modeled by the USGS PSHA program based on probabilistic concepts. The seismic sources used in the analyses were based on the latest researches published by National Center for Earthquake Studies (PuSGeN) in 2017. The study reveals that, generally, North Java Offshore Indonesia can be categorized as seismic zone 1 and 2 and East Madura as seismic zone 3 in accordance to ISO 19901-2.

Keywords: seismic hazard map, North Java offshore, ISO 19901-2

1. Introduction

Earthquake is one of the natural disasters in the world that has claimed many lives and causes massive material loss. Generally, the impact caused by earthquake will increase significantly along with the increase in population growth in an area, especially in very active tectonic regions such as Indonesia. Indonesia is located in a tectonically very active area at the point of convergence of three major plates and nine smaller plates [1]. The interactions among the tectonic plates cause Indonesia as one of the most seismically active regions in the world. Past experiences show that most of casualties and losses on earthquakes events are caused by the damage/failure of infrastructures/buildings.

Seismic design code for building in Indonesia regularly updated by the government of Indonesia. It is also supported and continually developed by so many researches in recent years [1]. However, still no standard code has been developed specifically for designing earthquake resistance structures for offshore platforms in Indonesia. Most of the platforms in Indonesia are designed using API RP 2A WSD as standard guideline. There are two earthquake levels are introduced in the code, i.e. Strength Level

Earthquakes (SLE) and Ductility Level Earthquake (DLE). This guideline does not explicitly state the return periods and the procedures for developing those two levels of earthquakes.

ISO 19901-2 proposes a more detailed procedure in determining the earthquake load for use in designing earthquake resistance for offshore structures. Two levels of seismic design are used in ISO guideline: Extreme Level Earthquakes (ELE) and Abnormal Level Earthquake (ALE). There are two alternatives procedures are described in ISO 19901-2 for developing those two levels of earthquake; the simplified method, and the detailed method. A simplified method is used when seismic considerations are unlikely to govern the design of a structure, while the detailed method will be used when seismic considerations have a significant impact on the design [6].

ISO 19901-2 has provided seismic maps for a 1.0s oscillator period and for a 0.2s oscillator period respectively for worldwide including Indonesia. These maps are developed based on 1.000 years return period of earthquake. The maps can be used for determining site seismic zones and for developing ELE and ALE using simplified method. Unfortunately, the maps are very rough with low- resolution images. Therefore, these maps may be insufficient or unreliable to be used in seismic design.

The paper presents a development of seismic hazard maps for 1.000 years return period for North Java Offshore Indonesia. Two spectral hazard maps for a 1.0s oscillator period and for a 0.2s oscillator period will be developed using probabilistic approach. The seismic sources geometries and parameters used in the analysis will be based on the latest data and information such as from National Center for Earthquake Studies (PuSGeN) and/or other published papers.

2. Seismotectonic model

Development of spectral hazard maps of North Java Offshore Indonesia requires information about seismotectonic setting which is evaluated based on three categories of source models. The source models are comprised of background seismicity including shallow and deep background, fault sources, and subduction sources. The seismic sources are described in the following sections.

2.1. Background source

Background seismicity is evaluated to accommodate the recorded earthquake incidents with difficult/unclear seismotectonic data. The background source is accommodated for low to medium scale earthquakes into a grid. In the model, a small-scale earthquake is defined as an earthquake with a magnitude of no less than 4.5.

The background model is divided into two types based on its depth; shallow background, and deep background. Shallow background is intended for earthquakes with maximum depth of 50 km. In this model, shallow background is divided into two intervals (0-25 km and 25-50 km). The maximum magnitude used for shallow background is 6.4. The deep background sources are used for modeling the earthquake from Benioff zones (intraslab earthquake). This zone is divided into 4 intervals (50-100 km, 100-150 km, 150-200 km, and 200-300 km). The maximum magnitudes used for deep background are determined based on several data such as historical earthquake, slip rate, and other seismotectonic conditions.

The historical earthquake data for use in background seismicity are shown in Figure 1. In the research, historical earthquake events are based on PuSGeN catalogue that covers the period between 1900 to 2016.

2.2. Fault source.

Fault or line sources represent individual faults for which data are sufficient to determine maximum earthquake magnitudes distributions and slip rate estimates [3]. The seismic source parameters required in seismic hazard analyses are the earthquake mechanism, slip-rate, maximum magnitude of earthquake, and the geometry of fault such as trace coordinate, dip angle, width, top, and bottom depth of fault. In the model, the fault mechanisms that can be identified are strike-slip, reverse, and normal. Fault sources used the research are listed in Table 1, while the fault segments can be seen in Figure 2.

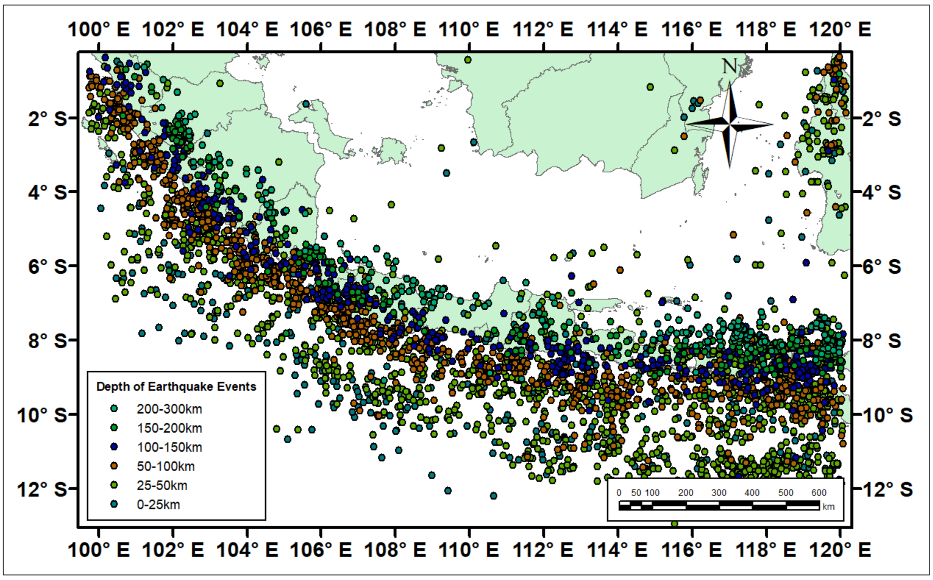

Figure 1. Historical Earthquake around Offshore Java. [2]

Table 1. Fault Sources. [2]

No	Fault Segment	Slip-rate (mm/yr)	Mechanism	Dip (°)	M_{max}
1	Cimandiri Fault - Cimandiri	0.55	Reverse	45	6.7
2	Cimandiri Fault - Nyalindung - Cibeber	0.4	Reverse	45	6.5
3	Cimandiri Fault - Rajamandala	0.1	Strike-slip	90	6.6
4	Lembang Fault - Lembang	2.0	Strike-slip	90	6.8
5	Baribis - Kendeng Fold - Thrust Zone - Subang	0.1	Reverse	45	6.6
6	Baribis - Kendeng Fold - Thrust Zone - Tegal	0.1	Reverse	45	6.5
7	Baribis - Kendeng Fold - Thrust Zone - Pekalongan	0.1	Reverse	45	6.6
8	Baribis - Kendeng Fold - Thrust Zone - Weleri	0.1	Reverse	45	6.6
9	Baribis - Kendeng Fold - Thrust Zone - Semarang	0.1	Reverse	45	6.6
10	Baribis - Kendeng Fold - Thrust Zone - Demak	0.1	Reverse	45	6.6
11	Baribis - Kendeng Fold - Thrust Zone - Purwodadi	0.1	Reverse	45	6.7
12	Baribis - Kendeng Fold - Thrust Zone - Cepu	0.1	Reverse	45	7.1
13	Baribis - Kendeng Fold - Thrust Zone - Waru	0.05	Reverse	45	6.9
14	Baribis - Kendeng Fold - Thrust Zone - Surabaya	0.05	Reverse	45	6.5
15	Baribis - Kendeng Fold - Thrust Zone - Blumbang	0.05	Reverse	45	6.6
16	Ciremai – Strike-slip Fault	0.1	Strike-slip	90	6.6
17	Ajibarang – Strike-slip Fault	0.1	Strike-slip	90	6.6
18	Opak - Strike Slip Fault	0.75	Strike-slip	60	7.0
19	Merapi - Merbabu - Strike Slip Fault	0.1	Strike-slip	90	6.8
20	Pati Thrust	0.1	Strike-slip	90	6.9
21	Sumatera Fault - Sianok	14.0	Strike-slip	90	7.4
22	Sumatera Fault - Sumani	14.0	Strike-slip	90	7.2
23	Sumatera Fault - Suliti	14.0	Strike-slip	90	7.4
24	Sumatera Fault - Siulak	14.0	Strike-slip	90	7.3
25	Sumatera Fault - Dikit	12.0	Strike-slip	90	7.2
26	Sumatera Fault - Ketaun	12.0	Strike-slip	90	7.4
27	Sumatera Fault - Musi	13.5	Strike-slip	90	7.3
28	Sumatera Fault - Manna	13.5	Strike-slip	90	7.4
29	Mentawai Fault - Mentawai	5.0	Reverse	45	8.5
30	Mentawai Fault - Enggano	5.0	Reverse	45	7.7
31	Sumatera Fault - Kumering North	12.5	Strike-slip	90	7.5
32	Sumatera Fault - Kumering South	12.5	Strike-slip	90	7.2
33	Sumatera Fault - Semangko Barat A	8.0	Strike-slip	90	7.4
34	Sumatera Fault - Semangko Timur B	3.0	Strike-slip	90	6.9

No	Fault Segment	Slip-rate (mm/yr)	Mechanism	Dip (°)	M_{max}
35	Sumbawa Strait Strike-slip Fault - Central	0.5	Strike-slip	90	7.4
36	Sumbawa Strait Strike-slip Fault - South2	0.5	Strike-slip	90	6.9
37	Sumbawa Strait Strike-slip Fault - South1	0.5	Strike-slip	90	7.0
38	Lombok Strait Strike-slip Fault - North	0.5	Strike-slip	90	7.6
39	Lombok Strait Strike-slip Fault - Central	0.5	Strike-slip	90	7.6
40	Sumba Strike-slip - 1	0.5	Strike-slip	90	7.3
41	Flores Backarc Thrust - Bali	13.9	Reverse	45	7.3
42	Sumba Strike-slip - 2	0.5	Strike-slip	90	7.0
43	Sumba Strike-slip - 3	0.5	Strike-slip	90	6.7
44	Sumba Strike-slip - 4	0.5	Strike-slip	90	6.8
45	Sumba Strike-slip - 5	0.5	Strike-slip	90	7.0
46	Flores Backarc Thrust - Lombok Sumbawa	19.8	Reverse	45	7.9
47	Makasar Strait Thrust - North	2.0	Reverse	45	7.12
48	Makasar Strait Thrust - Central	3.0	Reverse	45	7.38
49	Makasar Strait Thrust - Mamuju	6.0	Reverse	45	7.02
50	Makasar Strait Thrust - Somba	6.0	Reverse	45	7.35
51	Palukoro Fault - Moa	33.0	Strike-slip	90	7.19
52	Palukoro Fault - Saluki	33.0	Strike-slip	90	6.99
53	Palukoro Fault - Palu	33.0	Strike-slip	90	6.81
54	Walanae	0.1	Strike-slip	90	7.0
55	Palolo-A	0.1	Normal	60	6.44
56	Sumatera Fault - Ujung Kulon A	10.0	Strike-slip	90	7.4
57	Sumatera Fault - Ujung Kulon B	10.0	Strike-slip	90	7.7
58	Sumatera Fault - Semangko Barat B	8.0	Strike-slip	90	7.4
59	Sumatera Fault - Semangko Graben	3.0	Normal	60	7.1
60	RMKS Fault - West	3.0	Strike-slip	90	7.9
61	RMKS Fault - East	3.0	Strike-slip	90	7.8
62	Sape Strike-slip	0.5	Strike-slip	90	6.7
63	Bondowatu Fault	0.5	Normal	60	6.5
64	Teluk Panas Fault - North	0.5	Strike-slip	90	7.7
65	Bawean Fault	0.5	Strike-slip	90	7.6
66	Meratus	0.2	Reverse	45	7.0

2.3. Subduction source

The subduction source models are derived from seismotectonic data that have been well identified. A relatively simple mechanism of subduction occurs where oceanic crust is subducted beneath the continental platform in Sumatera, Java, and Nusa Tenggara Earthquake events considered in subduction sources are earthquake events with focal depths less than 50 km. Subduction sources model for North Java Offshore is shown in Figure 3, while the parameters are listed in Table 2**Error! Reference source not found.Error! Reference source not found.**.

Table 2. Summary of Subduction Sources. [2]

No	Subduction Segmentation (Megathrust)	Parameter		
		a	*b*	M_w
M1	Mentawai-Siberut	4.25	0.85	8.9
M2	Pagai	3.02	0.63	8.9
M3	Enggano	5.57	1.05	8.4
M4	Sunda Strait	5.99	1.15	8.7
M5	West Central Java	5.55	1.08	8.7
M6	East Java	5.63	1.08	8.7
M7	Sumba	5.63	1.11	8.5

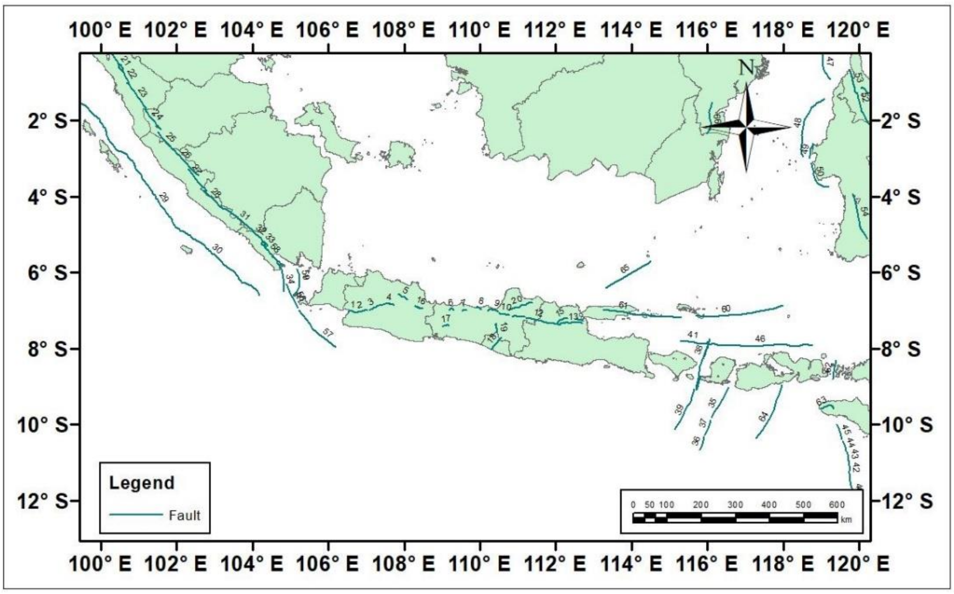

Figure 2. Fault Sources. [2]

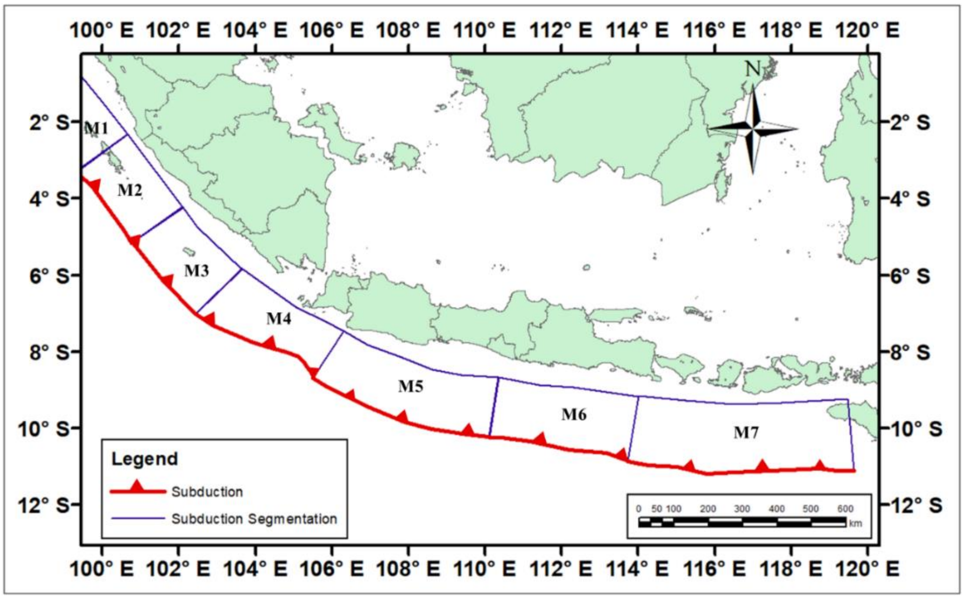

Figure 3. Subduction Zone Sources. [2]

3. Seismic hazard analysis

3.1. Probabilistic Seismic Hazard Analysis (PSHA)

The PSHA method is developed by McGuire [7] based on the total probability concept developed by Cornell [8][4]. The theorem of total probability assumes earthquake size (magnitude, *M*) and location (defines by range from hypocentre, *R*) as continuous independent random variable. Formula of total probability theorem that intensity of a ground motion *I* will exceed a certain value of *i* represented by:

$$P[I > i] = \iint P[I > i \mid M, R] f_M(m) f_R(r)\, dm\, dr \tag{1}$$

where $P[I > i \mid M, R]$ is conditional probability of intensity I will exceed value i at certain location of R and magnitude of M. While $f_M(m)$ and $f_R(r)$ are probability density functions for M and R [4].

3.2. Attenuation function

The relation between the earthquake source parameters (such as location of the sources, the magnitude, slip-rate) and the ground motion parameters (such as acceleration, velocity, and displacement) at site location is represented by the attenuation function. At this moment, there is no attenuation function specifically developed for Indonesia region. The only way is to adapt attenuation function derived in another region, which is similar to Indonesia region tectonically and geologically [5]. The attenuation functions used in this study are based on the functions proposed by PuSGeN [2] as shown in Table 3.

Table 3. Attenuation Functions Used in Seismic Hazard Analysis.

Source Model	Attenuation function
a) Shallow crustal (fault and shallow background)	(1) Boore - Atkinson NGA. (2008) [11] (2) Campbell - Bozorgnia NGA. (2008) [12] (3) Chiou - Youngs NGA. (2008) [13]
b) Deep background	(1) Atkinson - Boore intraslab seismicity Cascadia (2003) [14] (2) Youngs et al. (1997) [15] (3) Atkinson - Boore intraslab seismicity worldwide data (2003) [14]
c) Subduction sources	(1) BC Hydro (2012) [16] (2) Atkinson - Boore (2003) [14] (3) Zhao et al. (2006) [17]

4. Seismic zonation

According to ISO 19901-2, the complexity of a seismic action evaluation and the associated design procedure depends on the structure's seismic risk category (SRC) [6]. The SRC is determined by two aspects; exposure level of the structure and seismic zone. The structure exposure levels are determined by consideration of life-safety and consequences of failure. There are three (3) exposure levels in accordance with API RP2A, as follows: L1 for high failure consequence, fully manned, large facility; L2 for moderate consequence, lightly manned, moderate pollution potential; L3 for low consequence, unmanned, satellite, no pollution potential.

The seismic zone is determined by the earthquake spectral acceleration with a period of 1.0 seconds (S_a (1.0)) for a 1000-year return period as shown in Table 4. Based on the exposure level and the site seismic zone, the SRC is determined as listed in Table 5. According to the standard, the SRC is used to determine whether a simplified or detailed seismic action procedure required for seismic design. For this purpose, this study will develop maps of earthquake spectral acceleration at a period of 1.0 second (S_a (1.0)) for a 1000-year return period and to determine seismic zones for North Java Offshore.

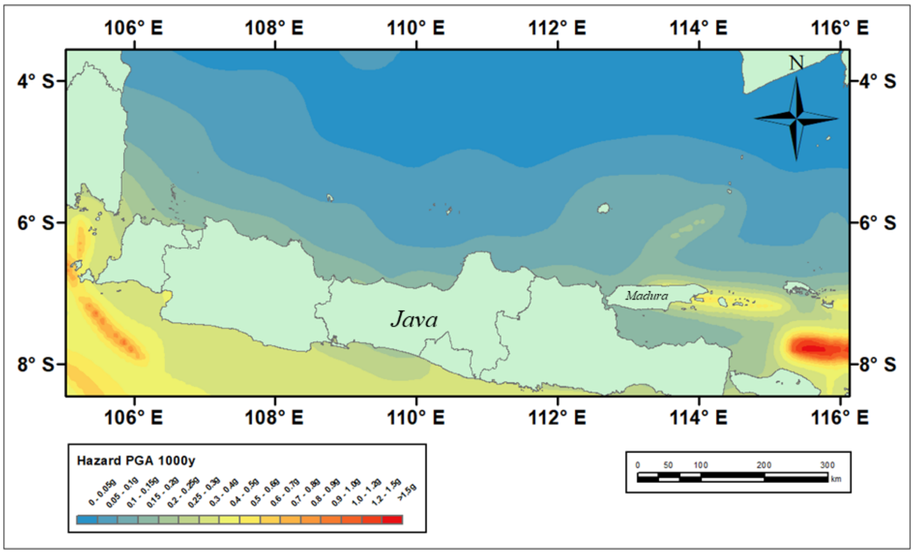

Figure 4. Map of PGA of North Java Offshore Indonesia for 1000 years return period.

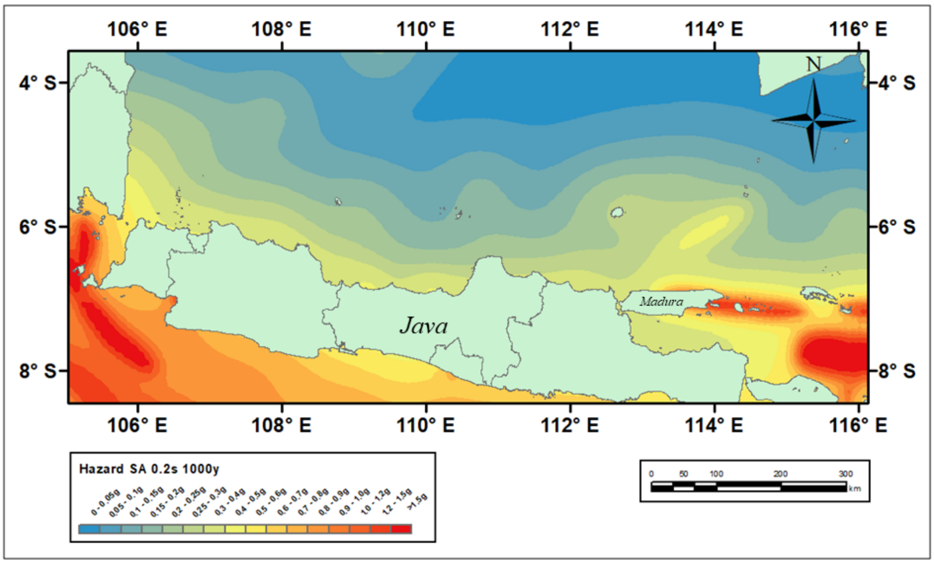

Figure 5. Map of 0.2-s spectral acceleration of North Java Offshore Indonesia for 1000 years return period.

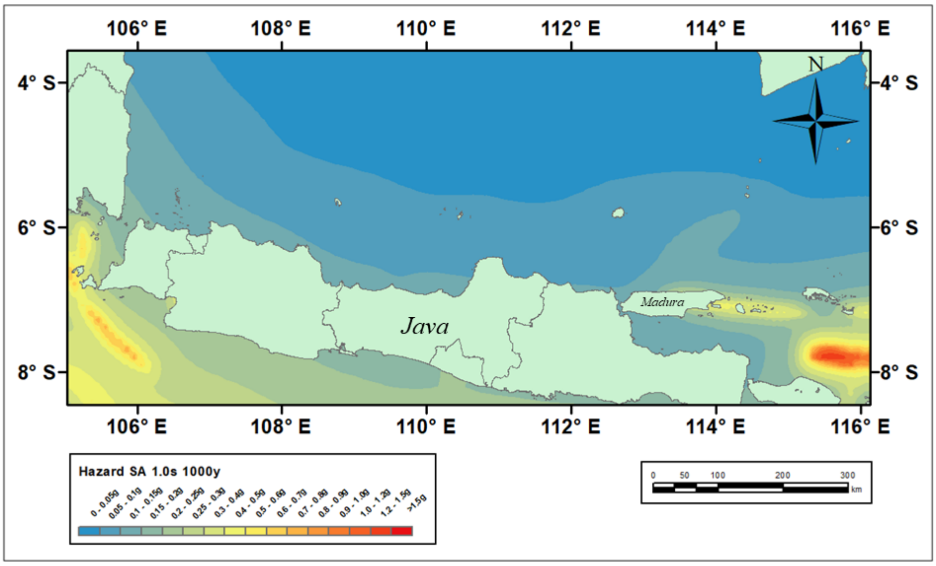

Figure 6. Map of 1.0-s spectral acceleration of North Java Offshore Indonesia for 1000 years return period.

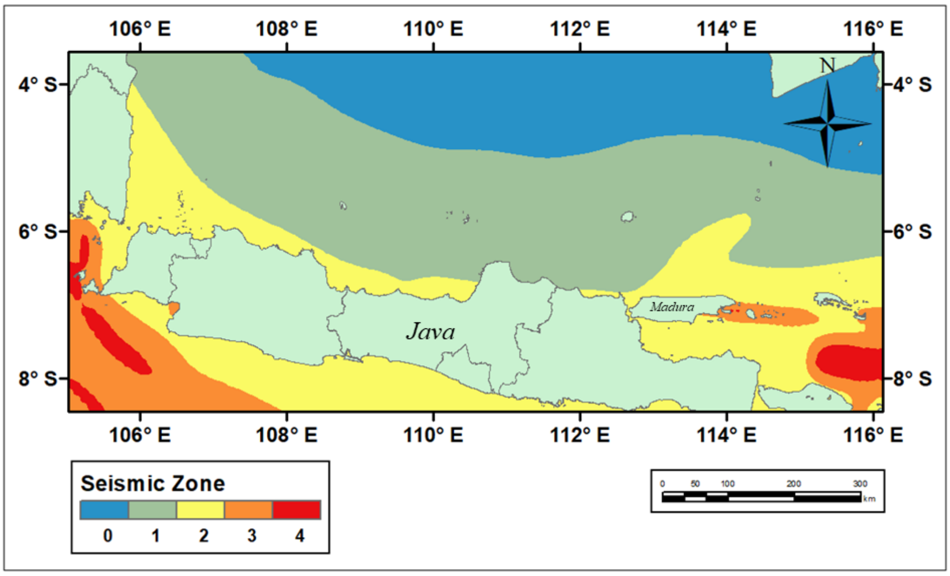

Figure 7. Map of seismic zone of North Java Offshore Indonesia based on ISO 19901-2:2004.

Table 4. Site Seismic Zone Based on ISO 19901-2:2004. [6]

S_a (1.0)	Site Seismic Zone
< 0.03g	0
0.03g – 0.10g	1
0.11g – 0.25g	2
0.26g – 0.45g	3
> 0.45g	4

Table 5. Seismic Risk Category, SRC. [6]

Site Seismic zone	Exposure Level		
	L3	L2	L1
0	SRC 1	SRC 1	SRC 1
1	SRC 2	SRC 2	SRC 3
2	SRC 2	SRC 2	SRC 4
3	SRC 2	SRC 3	SRC 4
4	SRC 3	SRC 4	SRC 4

5. Results and discussions

The research is carried out using USGS PSHA Software [10] by combining results from each different seismic source model. Output from the software are spectral acceleration values at some point location along area of North West Java Offshore. The output values of spectral acceleration then arranged based on the ranges of acceleration to develop the seismic hazard maps. The seismic hazard maps for Peak Ground Acceleration (PGA) at bedrock with 5% damping and spectral acceleration at 0.2-s and 1.0-s period for 1000-years return period are shown in Figure 4 to Figure 6.

As shown in the figures, the result for PGA's at North West Java ranges between 0.1g and 0.25g. The spectral accelerations for the 0.2s and 1.0s period of North West Java range from 0.25g to 0.5g and from 0.1g to 0.2g, respectively.

The ranges of seismic hazard values for East Madura offshore are generally higher than North West Java offshore. The PGA at bedrock varies between 0.15g and 0.5g. The spectral acceleration for the 0.2s and 1.0s period range from 0.4g to 1.5g and from 0.2g to 0.5g, respectively. The seismic hazard values for East Madura are generally higher than in North West Java. This is probably due to the East Madura offshore mostly affected by Rembang-Madura-Kangean-Sakala (RMKS) fault.

Based on the spectral hazard maps at 1.0s period shown in Figure 7, the North Java Offshore can be classified as Seismic Zone 1 or 2, whereas East Madura as Seismic Zone 3 following ISO 19901-2.

6. Conclusions

The seismic hazard analysis has been carried out using a probabilistic approach. The seismic sources geometries and parameters used in the analysis are based on the latest data and information, such as from the National Center for Earthquake Studies (PuSGeN) and/or other published papers. The results show generally the seismic hazard values for East Madura are relatively higher than North West Java. This is due to the East Madura offshore mostly affected by RMKS fault.

Finally, the seismic zone is determined by following ISO 19901-2. Based on the spectral hazard maps at 1.0s period, the North Java Offshore can be classified as Seismic Zone 1 or 2, whereas East Madura as Seismic Zone 3 following ISO 19901-2.

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