Probabilistic Seismic Hazard Analysis of East Java Region, Indonesia

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***Abstract*—Seismic hazard analysis has been conducted in the region of East Java by using the Probabilistic Seismic Hazard Analysis (PSHA). This research is used to perform seismic hazard analysis with the modeling of 3-dimensional seismic sources for return period of 500 years. PSHA analysis for East Java region performed at T = 0 second (PGA), T = 0.2 second (short period) and T = 1 seconds (long period). Model of the earthquake catalog used in this analysis is the historical earthquake from 1900 to July 2011, with the area of 5°SL – 12°SL and 105°WL - 116°WL taken from MCGA, USGS which consists of NEIC-USGS, NOAA, the PDQ and the combined catalog of the Advanced National Seismic System (ANSS), as well as the catalog of the International Seismological Center (ISC) and Engdahl, vander Hilst, and Buland (EHB) with a depth of 0-300 km and magnitude ≥ 5MW.**

The results showed that for the acceleration of bedrock at T = 0 second (PGA), T=0.2 seconds (short period) and T = 1 seconds (long period) have values between 0.09 g - 0.29 g, 0.19 g - 0.61 g, and 0.06 g - 0.29 g respectively. The districts having lowest and highest PGA are Sumenep and Pacitan respectively.

***Index Terms*—PSHA, Seismic Hazard, Peak Ground Acceleration (PGA), East Java.**

I. Introduction

Indonesia lies in a highly active tectonic zone due to three large plates and one micro plate world which meet in the region of Indonesia; the Eurasian plate, the Indo-Australian plate, Pacific plate and the Philipine micro plate. All three of these plates form a single line plates in Indonesia, as shown in Fig. 1.

Indonesia has a lot of local fault-fracture, which is also potentially damage the building, when the earthquake happened. The fault are shown on the map Geological Agency, which are: Semangko, Cimandiri, Lembang, Lasem, Pati, Tulungagung, Lumajang, and Banyuputih faults respectively. In this case, government should play an important role in the risk reduction (mitigation) caused by the earthquake. East Java is one of the province that has a high risk, because East Java is close to the subduction zone line and also many faults (local faults) which have not been identified accurately. Therefore, it should be that infrastructure plannings in East Java are desained well to reduce the impact of earthquake.

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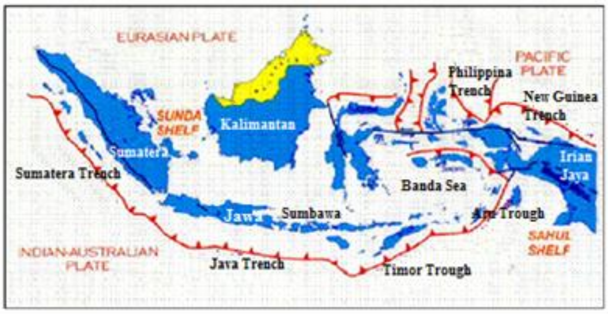

Fig. 1. Tectonic position and setting of Indonesia

The earthquake experts continuely develop methods to calculate the risk of earthquke in the infrastructure. One of the methods is *Probabilistic Seismic Hazard Analysis* (PSHA). This method uses *probabilistic seismic hazard analysis* program (USGS PSHA-2007), with possibilty of 10% exceeded in the 50 years of building or equal to 500 years return period of earthquake. The model used is based on earthquake catalog research area in the island of Java from 1900 until the end of July 2011 with a value of magnitude ≥ 5 *Mw* and maximum depht of 300 km.

II. Tectonic Setting of East JAVA.

Based on seismotectonic, East Java affected by subduction zones or the meeting of two tectonic plates that are along the southern of East Java. Subduction zones which are located in the southern region of Indonesia are known as the source of the Sunda arc earthquake stretching from the west of Andaman island to the East part of Banda island. In the eastern part of the Sunda arc, it spans the Banda arc that starts from the eastern part of Sumbawa to Timor islands, which is counter-clockwise curved towards the north, pass the Seram until Buru islands.

In addition, Seismic activity in East Java is not only affected by the subduction zone located in the south of the island of Java, but also affected by the fault activity, both locally and regionally. For the fault in East Java, there are still many that have not been properly identified, and research is being carried out by the Geological Agency to date. Based on fault maps obtained from the Geological Agency, there are some faults that are being researched in the area of East Java, such as Tulungagung, Lumajang and Banyu Putih faults respectively. All three faults are included into the B class, with the maximum *magnitude* of ≥ 6.5 – 7 *Mw* with the *slip rate* <2 hingga <5 mm/year

The magnitude of the seismic hazard in East Java is not only solely affected by the fault in East Java and microseismic [1], [2], but also affected by the fault activity that was around East Java such as Lasem, Pati and Opak faults. Location of the

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faults are shown in Fig. 2.

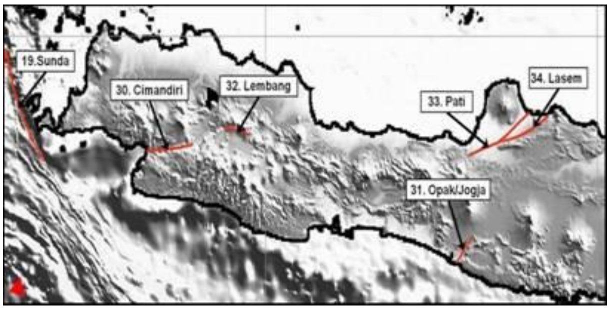

Fig. 2. Faults in Java island [5]

III. Earthquak Source Zone

Earthquake source modeling or seismotectonic models are necessary as relations earthquake event data with the model calculations used in determining the level of earthquake risk. There are three models of earthquake sources that can be distinguished for Indonesia [3], [4], namely :

- Subduction zone

The path, where earthquake happen around the two pletes, where oceanic plate enter the continental plate or both of continental plates pushed each other.

- Crustal fault zone

The earthquake occurs at the shallow crustal.

- Spread zone

The path that is assumed as the earthquake source regions having the same seismic potential. Examples of these earthquakes are earthquakes related to tectonic activity behind the arc (back arc), back arc basin, microscopic fragments continent.

IV. Seismic Hazard Analysis

Hazard is defined as potential hazards or threats that are the result of interaction between extreme natural events (which is still a potential) to the system of the human environment (in the form of reality). Seismic hazard and seismic risk has fundamental differences. Seismic hazard is the physical form of the hazard itself, such as ground motion, fault movement, liquefaction, etc., which can pose a danger. In addition the seismic risk is the possibility of loss of life or property loss and caused by seismic hazard. If there is no loss of life or material caused by an earthquake, it can be said that the seismic risk is relatively non-existent, no matter how large seismic hazard there.

Probabilistic seismic hazard analysis (PSHA) in principle deterministic is an analysis with a variety of scenarios, and is based not only on the seismic parameters that produce the largest ground motion. This method is a method used in seismic hazard analysis based on the definition of a probability distribution function that takes into account and incorporate the uncertainty of the scale of the earthquake occurrence, location, and frequency of occurrence, to get the whole picture about the level of risk in terms of a location.

PSHA Method was developed by Cornell in 1986, followed by Merz and Cornell in 1973 which was further developed by Mc.Guire in 1976. This theory assumes an earthquake magnitude M and distance R as a continuous independent random variables. The general form of the total probability theory can be stated as follows:

$$P[I \geq i] = \iint_{r\,m} P[I \geq i \mid m\, dan\, r]\, f_M(m)\, f_R(r)\, dm\, dr \qquad (1)$$

where:

f_M : distribution function of magnitude

f_R : distribution function of hypocentre distance

$P[I \geq i \mid m \text{ dan } r]$: Probability of intensity I.

V. Earthquake Risk

Earthquake risk is Probability of exceendance an earthquake with certain intensity and certain periodicity for the building, which is:

$$Rn = 1 - (1 - Ra)^N \qquad (2)$$

where :

Rn = earthquakerisk

Ra = yearly risk 1/T

N = buildng age

T = average of earthquake periodicity.

TABEL I: Relationship of Erathquake Risk Parameters.

Annual rate	*T* (Periodicity)	R_n (Earthquake risk value)	*N* (building age)
	(years)	(%)	(years)
0.0021050	475	10	50
0.0004040	2.475	2	50
0.0002020	4.950	2	100

VI. Field Site Study

This study was conducted from July to December 2011 at the Meteorology, Climatology and Geophysics Agencies (BMKG), Jakarta. The data used is the earthquake data with South latitude of 5^o - 12^o and West longitude 105^o - 116^o, East Java, starting from 1900 to July 2011.. Minimum magnitude scale used is Mw ≥ 5 with a maximum depth of 300 km. It is assumed that earthquakes with depths greater than 300 km does not cause deleterious effects on the surface. Earthquake data used was collected from a variety of agencies, both nationally and internationally among others, the Meteorology, Climatology and Geophysics (BMKG), Indonesia, USGS catalog : NEIC, NOAA, PDQ, ANSS (*The Advanced National Seismic System*), *International Seismological Center* (ISC) and *Engdahl, vander Hilst, and Buland* (EHB).

VII. Spectral Hazard Curve

Analysis results of the Seismic hazard probabilistics for the some cities in East Java were showed in hazard curves. This analysis is to know the contribution of each significant earthquake source which is very vulnerable for the investigated site. Hazard curve is relationship between annual rate exceedance to the *hazard* (ground acceleration).

Fig. 3 is hazard curve of Malang city. From this Figure it is indicated that the highest annual rate exeedance is deep background earthquake. This earthquake occurs at *benioff* zone which is between 50 and 300 km depth.

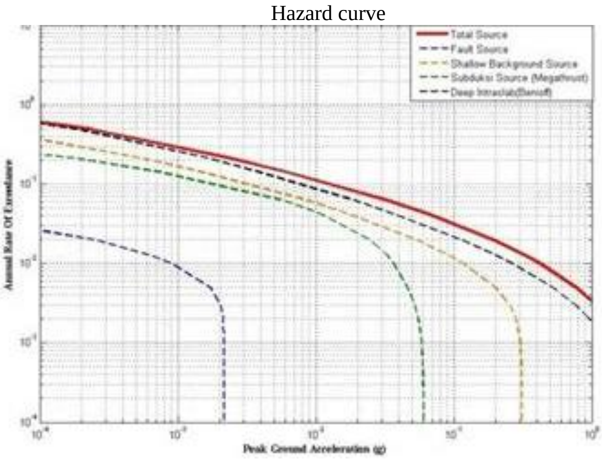

Fig. 3. Peak Ground Acceleration of bedrock in Malang city.

Surabaya city, which is central city of East Java, has the shallow background earthquake. The earthquake occuring in this situation has a depth between 50 and 300 km. Because the value of peak ground acceleration resulting from hazard curve is small, so Surabaya city is quite safe from the earthquake. Figure 4 is the hazard curve of Surabaya city.

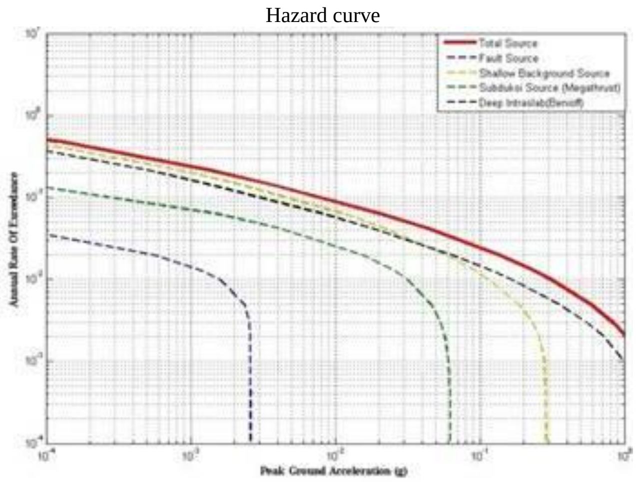

Fig. 4. Peak Ground Acceleration of bedrock in Surabaya city.

TABLE II: NAME OF REGENCIES AND CITIES IN THE EAST JAVA PROVINCE.

No	Regency	No	Regency	No	Regency
1	Bangkalan	11	Jember	21	Bojonegoro
2	Banyuwangi	12	Jombang	22	Bondowoso
3	Blitar	13	Kediri	23	Gresik
4	Lamongan	14	Lumajang	24	Madiun
5	Magetan	15	Malang	25	Mojokerto
6	Nganjuk	16	Ngawi	26	Pacitan
7	Pamekasan	17	Pasuruan	27	Ponorogo
8	Probolinggo	18	Sampang	29	Sidoarjo
9	Situbondo	19	Sumenep	29	Trenggalek
10	Tuban	20	Tulungagung		

No	City
30	Batu
31	Blitar
32	Kediri
33	Madiun
34	Malang
35	Mojokerto
36	Pasuruan
37	Probolinggo
38	Surabaya

VIII. RESULTS

The results of the analysis are obtained in the form of peak ground acceleration (PGA) at $T = 0$ seconds, $T = 0.2$ sec (short period), and $T = 1$ second (long period) for the probability exceeded 10% in 50-year life of the building or the equivalent 500-year return period earthquake. Range of maximum acceleration value due to the earthquake background ranged from 0.04g - 0.35g, the maximum value of the acceleration caused by the earthquake faulting ranged from 0.025g - 0.235g, and the maximum value of acceleration due to subduction earthquake source / megathrust ranged between 0.043g - 0.35g.

There are 38 of Regencies and Cities in East Java. The Regency and cities that have low and high PGA are only listed in the Table II below:

IX. CONCLUSSION

Probabilistic Seismic Hazard Analysis or PSHA is a method used in seismic hazard analysis based on the definition of a probability distribution function that takes into account and incorporate the uncertainty of the scale of the earthquake occurrence, location, and frequency of occurrence, to get the whole picture about the level of risk in terms of a location. Based on the analysis of earthquake data from 1900 to July 2011 with probabilistic seismic hazard analysis methods with the help of USGS PSHA-2007, it was concluded as follows:

1) Analysis of seismic hazard in East Java produces PGA values (T = 0 seconds) in the bedrock between 0.09g and 0.29g, for a short period (T = 0.2 sec) has a range from 0.19g to 0.61g and for a long period (T = 1 sec) produce a value from 0.06g to 0.29g for the probability exceeded 10% in 50-year life of the building or the equivalent of 500 years return period earthquake.
2) Hazard curves (hazard curve) in East Java bedrock for some major cities such as Surabaya and Malang shows that, in general, the earthquake background dominates or contributes greatly to the hazards that exist in East Java.
3) Regencies / cities in East Java that has the lowest value of PGA is Sumenep, 0.1270 g and which has the highest PGA value is Pacitan, 0.2768g.

From the earthquake acceleration values obtained, it indicated that several cities in East Java is very prone to earthquakes such as the city of Malang, Tulungagung and Pacitan. So in making the building or other infrastructure facilities, it is expected to always consider the factor of the acceleration of earthquake in the bedrock as a benchmark in construction.

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