Semi-probabilistic Method in Analysing Kendeng Fault Earthquake Hazard in Surabaya, East Java

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Abstract. Surabaya is one of the cities in Indonesia which is prone to earthquakes. This condition is caused by the megathrust zone located in southern Java. In addition, there is an active fault that passes through East Java, namely the Kendeng fault, which to be the source of underground earthquakes. The part of Kendeng Fault that is situated near Surabaya is classified as the Surabaya segment and Waru segment. Based on this condition, research was carried out to analyze the earthquake hazard caused by Kendeng Fault in Surabaya city. A semi-probabilistic method is used in this research, as it can calculate the Peak Ground Acceleration (PGA) and earthquake intensity by considering the range from the measurement point to every point on the fault. The PGA measurement is using the equation of attenuation function. USGS Vs30 data, East Java Province base map, and Surabaya geological map are the data that were used to support the research. The result of earthquake hazard analysis gives the highest ground acceleration potential region is located in the north-western Surabaya subdistricts, this includes Sambikeremp and Lakarsantri subdistricts. The high value of PGA and earthquake intensity is strongly affected by the short distance to the earthquake source.

1. Introduction
A recent study of East Java earthquakes stated that the megathrust earthquake was not the only earthquake source in East Java. According to [1], there is another earthquake source originating from subsurface faults. As mentioned by [2], the East Java region is passed through by several active faults, among them are Kendeng fault (consists of Blambangan, Waru, and Surabaya segments), Pasuruan fault, Probolinggo fault, and Wonorejo fault. Kendeng fault is an active fault that extends from the east of East Java to the west of Central Java [1]. This fault is divided into several segments and consists of thrusts and folds [3]. According to the preceding study by [4], the two of its segments, Surabaya and Waru segments, pass through Surabaya city which is a vital district in East Java, as it acts as the capital city and economic booster of the province. In addition, a preceding study by [5] found that Surabaya is vulnerable to liquefaction due to its geological setting. Based on these facts, earthquake hazard analysis is necessary to reduce the damage impacts in Surabaya.

Previous research on earthquake hazards in the East Java region has been carried out using deterministic seismic hazard analysis method and calculating the distance of the closest earthquake source to a point [6]. Because of its uncertainties, calculating the distance from every point of the fault to a survey point is required to analyzing the earthquake. To complement the prior study, we applied a semi-probabilistic seismic hazard analysis by using the fault distance variations in the
observation area. As for the fault, we are focused on the Surabaya-segment Kendeng fault that passes through Surabaya.

This research is expected to complement previous researches and can be used as consideration for earthquake disaster mitigation in the city of Surabaya.

2. Methods
This study used Vs30, range, and earthquake magnitude as parameters. The Vs30 data is considered as it is an important parameter for evaluating the dynamic behavior of soil [7]. For starters, we constructed points to form a grid on the observation area and the earthquake source. Afterward, the distance calculation is performed on every observation station to every grid point on the earthquake source. The earthquake sources used in this study are the Surabaya fault and Waru fault.

![Figure 1. 3-D cross-section of the earthquake source.](image)

The points at the earthquake source are divided into three kinds of distances: furthest distance (max), average distance (mean), and closest distance (min). Previously mentioned parameters were subsequently inputted into Chiou-Youngs 2014 NGA, Campbell-Bozorgnia 2014 NGA, and Boore-Atkinson 2014 NGA attenuation functions calculation. These three functions work by considering the distance function as one of the main factors in the calculation [8]–[10].

The result of attenuation function calculation generates spectral acceleration (SA) response value on each point of the observation station. The example chart of SA response on one of the points of the observation station and each distance to Surabaya fault is shown in Figure 3.

The chart in Figure 3 shows that the variation in distance significantly affects the result of calculation using Chiou-Youngs attenuation function, as seen from the considerable difference between the distance variations in this equation. However, the inputted Vs30 value has little effect on the SA result since the frequency range in the Surabaya area is relatively small, and consequently didn’t use as a reference parameter on the SA comparison above.

In the weighting process using the logic tree feature, the difference in SA response values is used as the basis. The use of a logic tree is necessary due to the confounding factor in the processing data of seismic hazard analysis [11]. To make the logic tree model, the weightings specified for each equation are 0.4 for Campbell-Bozorgnia, 0.35 for Atkinson-Boore, and 0.25 for Chiou-Youngs.
Figure 2. Research Workflow Diagram.

Figure 3. Spectral acceleration response.
3. Result and Discussion
After calculating the peak ground acceleration (PGA) using the attenuation function, a PGA distribution map for each attenuation function is obtained.

The earthquake hazard in an area can be estimated by calculating the peak ground acceleration (PGA). Peak ground acceleration itself is defined as the maximum acceleration value experienced by an object when an earthquake occurs. PGA values in Fig. 5 are generated from calculations with three attenuation functions, namely Boore-Atkinson 2014 NGA, Chiou-Young 2014 NGA, and Campbell-Bozorgnia 2014 NGA.

From the results of the PGA calculation, we found that the areas on the western part of Surabaya experienced relatively high ground movement during the earthquake compared to the eastern part. This is due to the distance factor which is very influential on the PGA calculation. Because the two faults are
in the west, sub-districts in the western part such as Sambikerep and Lakarsantri will experience the most intense ground movement in almost all areas with PGA values ranging from 0.61 to 0.65 m/s².

Meanwhile, sub-districts of Pakal, Benowo, Tandes, Sukomanunggal, Dukuh Pakis, Wiyung, and Karang Pilang will experience PGA of 0.54 to 0.61 m/s².

Sub-districts in central Surabaya will experience moderate ground acceleration with the PGA of 0.46 to 0.54 m/s² which covers the area of Krembangan, Bubutan, Gubeng, and Tenggilis Mejoyo, along with parts of Asemrowo, Wonokromo, Wonocolo, Tegalsari, and Sawahan. Meanwhile, areas from the sub-districts of Pabean Cantian, Semampir, Kenjeran, parts of Tambaksari, Bulak, Mulyorejo, Sukolilo, Rungkut, and Gunung Anyar, will experience relatively low ground acceleration in most of their areas with the PGA of 0.31 to 0.46 m/s².

Furthermore, a calculation to predict the intensity of the earthquake probabilistically are also carried out at the return period of 2500 years, 1000 years, and 500 years. The objective of this calculation is to see how likely it is that an earthquake to occur in a certain period, or how long it is likely that an earthquake will occur again.

![Figure 6. The Distribution Map of PGA Value with Waru and Surabaya Fault Earthquake Source with Probability of Exceedance in 500 years.](image)

In the period exceeding 500 years, the probability of PGA experienced in Surabaya is around 0.025 – 0.079 m/s². In this period, the worst-affected areas still have a similar pattern to the general PGA distribution map. The worst damage will be experienced by areas in the western part of Surabaya which are close to the fault. Sub-districts with faults such as Pakal, Benowo, Tandes, Sukomanunggal, Sawahan, Tegalsari, Wonokromo, and Lakarsantri will experience PGA between 0.052 to 0.079 m/s². Meanwhile, the East Surabaya Region which is relatively far from the earthquake source will experience the maximum PGA of 0.033 m/s².
In the period exceeding 1000 years, the range of PGA values that can occur is around 0.037 - 0.155 \text{ m/s}^2. The areas with the worst potential damage are still concentrated in the same areas as in the 500 years, but with a higher value between 0.116 to 0.155 \text{ m/s}^2.

Figure 8. The Distribution Map of PGA Value with Waru and Surabaya Fault Earthquake Source with Probability of Exceedance in 2500 years.
In the period exceeding 2500 years, the range of PGA values that can occur is around 0.09 - 0.376 m/s^2. The value range for this return period is the highest when compared to prior return periods. From this, we can tell that the longer the earthquake return period is, the higher the PGA value. As for the areas that severely suffered, moderate and minor damage, still form the same contour pattern as the other return period maps.

4. Conclusion
Surabaya City has the potential to experience an earthquake because of the Surabaya Fault and the Waru Fault. The PGA value that will be experienced in the event of an earthquake is in the range of 0.31 to 0.65 m/s^2. The western part of Surabaya will be the worst-affected area if an earthquake occurs. Moreover, the probabilistic value of the earthquake will increase as the return period of the earthquake increases.

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