Strong ground motion simulation of the 27 May 2006 Yogyakarta earthquake using Empirical Green's Function

Yeremia Hanniel¹, Ade Anggraini¹, Agus Riyanto², Drajat Ngadmanto², Wiwit Suryanto¹*.

¹Seismology Research Group, Department of Physics, Universitas Gadjah Mada, Sekip Utara PO Box Bls 21, Yogyakarta Indonesia
²Meteorologi, Climatology and Geophysics Agency (BMKG) Yogyakarta Office, Jl.Wates Km 8, Gamping, Yogyakarta

* Corresponding author's e-mail: ws@ugm.ac.id

Abstract. On May 27, 2006, 05:54 am local time, a moderate crustal earthquake of magnitude Mw 6.3 struck the Yogyakarta province, especially in the Bantul regency in the south part of the province. The earthquake damaged or destroyed more than 400,000 houses and buildings and caused more than 5,700 people killed. Several earthquake stations recorded the ground vibration caused by the mainshock very well, except at the stations closest to the earthquake source, namely YOGI in Gamping, West of Yogyakarta, which experienced saturation due to significant vibration. Therefore, information about the maximum ground acceleration near the source is yet not known. We model the ground vibrations near the earthquake source using a stochastic Green's Function approach to obtain information about the ground motions' maximum amplitude. The earthquake source parameters we referred to is the moment tensor solution from the Harvard Moment Tensor. The calculations show that the amplitude is consistent with observations recorded at the BJI Banjarnegara (0.04g) and YOGI Yogyakarta (0.3g).

Keywords: empirical, stochastic Green's function, strong motion, Yogyakarta earthquake

1. Introduction

Yogyakarta Special Region is prone to earthquakes as the collision of the Indo-Australian plate with the Eurasian plate on its south results in high tectonic activity. The most recent major earthquake in Yogyakarta Special Region took place on 27 May 2006 at 05.54 WIB with a magnitude of Mw 6.4. This medium magnitude earthquake claims more than 5,700 lives and destroyed thousands of buildings, including residential house and public facilities [1]. Indonesian Meteorological and Geophysical Agency (BMG, now BMKG) had 27 seismic stations recording the Yogyakarta earthquake on 27 May 2006. However, data from several seismic recording stations were inadequate for analysis due to some instrument problems. Only YOGI (Yogyakarta) and BJI (Banjarnegara) seismic stations located less than 100 km away from the epicentre (Figure 1) could provide relevant data for analysis [2]. However, the mainshock's velocity seismogram recorded by the YOGI station showed the sign of waveform clipping. Typically, a clipped waveform must be excluded from further earthquake parameters.
estimation [3]. Applying correction procedures to this particular station is necessary as the YOGI station was the closest seismic recording station to the epicentre and damaged areas. Such near-field station potentially holds valuable information of earthquake source and local structure.

Stochastic Green's Function simulation performed in this study is part of the semi-empirical method in strong ground motion prediction. The semi-empirical process is widely known for predicting an earthquake's source, path, and site characteristics. Also, strong ground motion predicted by semi-empirical methods is in the range of critical engineering frequency [4].

![Figure 1. Regional map showing epicentre (blue beach ball) and two nearest seismic recording station from the epicentre (red diamond).](image)

2. **Stochastic Green's Function**

Ground motion spectrum contains information on how an earthquake physically occurs and how a wave propagates. Stochastic Green's function method simplifies numerous factors of ground motion spectrum to simple equations. The total spectrum of ground motion at a site \(Y(M_0, R, f)\) could be separated into:

\[
Y(M_0, R, f) = E(M_0, f)P(R, f)G(f)I(f),
\]

where \(E\) is earthquake source, \(P\) is wave propagation path, \(G\) is site effect, and \(I\) is instrument or type of motion, \(M_0\) is the seismic moment, \(R\) is closest distance to rupture surface, and \(f\) is frequency [5].

3. **Ground motion spectrum simulation**

Firstly, to obtain a simulated ground motion spectrum, we generated a random Gaussian white noise for a given duration based on earthquake event duration [6]. After that, the noise was windowed using an exponential window. We then transformed the windowed noise into the frequency domain using Fast Fourier Transform (FFT) to be normalized by the square root of the mean square amplitude spectrum [6]. Finally, we multiplied the normalized noise spectrum by the ground motion spectrum \((Y)\) and transformed it back into the time domain using FFT (Figure 2).
4. Results and discussion

We compared the final simulated acceleration waveforms with observed acceleration waveforms from N-S components in the YOGI and BJI case to measure how effective the method is in predicting the ground motion spectrum. Since YOGI records had clipped waveforms, we first compared simulated and observed acceleration waveforms in the BJI case. The bottom plot in Figure 3 shows similarities in waveform shapes and peak ground acceleration (PGA) values between simulated and observed acceleration waveforms at BJI. The simulated PGA value at BJI is around 0.469 g, which is only slightly larger than the observed PGA value at BJI.

The top plot in Figure 3 shows both simulated and observed acceleration waveforms have similar shapes and PGA values. However, the difference of simulated and observed PGA values in the YOGI case is more significant than in the BJI case. Simulated PGA value at YOGI is approximately 0.319 g, while observed PGA values at YOGI is about 0.364 g.
Figure 4. Comparison of simulated and observed acceleration spectrum in the frequency domain at YOGI and BJI.

Figure 4 shows that stochastic Green’s function effectively simulates ground motion in a frequency range starting from 0.1 Hz up to 10 Hz. It is the frequency band of interest in engineering seismology ($f > 0.1$ Hz) [5].

5. Conclusion
We have seen that the stochastic Green’s function method effectively predicts strong ground motion at a site or a region with limited earthquake data. It is also apparent that the simulated acceleration waveforms fall in a frequency range that becomes the main interest in engineering seismology.

Acknowledgement
BPPTN supported this research through Physics Department Research Grant 2018. Geophysics Laboratory of UGM provided computation facilities for this research.

References
[1] Diambama A D, Anggraini A, Nukman M, Lühr B G, Suryanto W 2019 Velocity structure of the earthquake zone of the M6.3 Yogyakarta earthquake 2006 from a seismic tomography study, Geophys J Int 216 (1) pp 439-452
[2] Elnashai A S, Sung J K, Gun J Y and Sidarta D 2007 The Yogyakarta Earthquake of May 27th, 2006 MAE Center Report Vol 7 (Urbana-Champaign: the University of Illinois at Urbana-Champaign) pp 15–22
[3] Yang W and Ben-Zion Y 2010 Seismol. Res. Lett. 81 53–61
[4] Tsurugi M 2013 Recipe for Predicting Ground Motion from Crustal Earthquake Pure and Applied Geophysics 168 1 pp 85-104
[5] Boore D M 2003 Simulation of Ground Motion Using the Stochastic Method Pure Appl. Geophys. 160 pp 635-676
[6] Boore D M 1983 Stochastic Simulation of High-frequency Ground Motions Based on Seismological Models of the Radiated Spectra Bull. Seismol. Soc. Am. 73 pp 1865-1894