Verification Modal Summation Technique for Synthetic and Observation Seismogram for Pidie Jaya Earthquake M6.5

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Abstract. Neo-Deterministic Seismic Hazard Assessment (NDSHA) method is a seismic hazard assessment method that has an advantage on realistic physical simulation of the source, propagation, and geological-geophysical structure. This simulation is capable on generating the synthetics seismograms at the sites that being observed. At the regional NDSHA scale, calculation of the strong ground motion is based on 1D modal summation technique because it is more efficient in computation. In this article, we verify the result of synthetic seismogram calculations with the result of field observations when Pidie Jaya earthquake on 7 December 2016 occurred with the moment magnitude of M6.5. Those data were recorded by broadband seismometers installed by BMKG (Indonesian Agency for Meteorology, Climatology and Geophysics). The result of the synthetic seismogram calculations verifies that some stations well show the suitability with observation while some other stations show the discrepancies with observation results. Based on the results of the observation of some stations, evidently 1D modal summation technique method has been well verified for thin sediment region (near the pre-tertiary basement), but less suitable for thick sediment region. The reason is that the 1D modal summation technique excludes the amplification effect of seismic wave occurring within thick sediment region. So, another approach is needed, e.g., 2D finite difference hybrid method, which is a part of local scale NDSHA method.

Keyword: Synthetic Seismogram, Pidie Jaya Earthquake

1. Introduction
Regarding the problem of ground shaking estimation lies in generic attenuation relations for PSHA procedure, the alternative NDSHA (Neo-Deterministic Seismic Hazard Assessment) procedure has advantages in calculating the strong ground motion from realistic model of synthetic seismograms respect to the source of specific properties. NDSHA may immediately and effectively accommodate any reliable information from those approaches in order to adequately compute the ground shaking maps[1][2][3]. Simplify NDSHA procedure can be divided into four steps as shown in Figure 1. The first step was identification of the fault or geographical areas that produce earthquakes and earthquake characteristics. The second step was determination of earthquake source definition for each cellular
area in seismogenic zones. The third step was computation of synthetic seismograms’ base of sources definition and structural characteristic sites. Finally, the fourth step was picking the maximum value from the synthetic seismograms as important parameters to be found which represent the strong ground motion, such as PGA (Peak Ground Acceleration) and PGV (Peak Ground Velocity).

2. Pidie Jaya (Pijay) Earthquake M6.5
In the early morning at 5.03 local time (UTC+7) there was a strong earthquake happened in Pidie Jaya area that shook Pidie Jaya, Pidie, Bireun. The earthquake happen in an area that was not expected to be an active fault previously and earthquake rarely happen there, so that the buildings in that area have a high vulnerability. The earthquake was felt to Banda Aceh, Medan and several other cities in the north of Sumatra Island. As reported by the BNPB, the dead victims were 104 people and 19,130 houses were reportedly damaged where 17,673 of them are in Pidie Jaya. A total of 387 people have been staying at the hospitals in Pidie, Pidie Jaya and Bireun for medical treatment due to injuries[4].

The great fault of Sumatra has been well known and it has produced many destructive earthquakes[5]. But the Pijay earthquake was a surprise one because it was far from the Sumatra fault zone[6] and there was an effort to make an additional fault line (black line in Figure 2) connected to the Sumatran fault [7].

![Figure 2. Active fault in Aceh](image-url)

![Figure 3. Epicenter location, focal mechanisms, and available data for seismograph and accelerograph when the Pidie Jaya earthquake occurs.](image-url)
3. Method

The computational algorithm is based on the modal summation technique for the generation of Rayleigh wave synthetic seismograms (radial and vertical component of motion). Equation 1 describes the asymptotic expression of the Fourier transform of the displacement for the radial \( u_r \) and the vertical \( u_z \) components of motion at a distance \( r \) from the source [8]. The radial component is described by

\[
\begin{align*}
\sum_{m=1}^{\infty} e^{-\frac{2\pi m}{\sigma} r} \frac{e^{-ik_m r}}{\sqrt{r}} \frac{1}{\sqrt{c_m^2 + m^2}} F_R(z, \omega) \frac{1}{\sqrt{c_m^2 + m^2}}
\end{align*}
\]

The beauty of the modal summation technique computer codes for layered, inelastic structural models lies in the separation of the calculation of the spectral quantities related with the medium properties (phase velocity \( c \), group velocity \( v \), energy integral \( I \) and complex wave number \( k \)) from those that describe the source and its position w.r.t. the sites of interest. Detail information and detailing governing mathematical formula for modal summation technique were explained by Panza [9].

Parameters involved for double-couple calculations are origin time, hypocenter magnitude and focal mechanics information. We used Pidie Jaya earthquake data obtained from USGS [10]. The earthquake epicenter was located at 5.283°N, 96.168°E with a focal depth of 13.5 km, which could be categorized as a shallow earthquake. The seismic mechanism was the right lateral strike slip with magnitude = 6.5 Mww, strike = 243°, dip = 81°, rake = 33°.

The synthetic seismograph from modal summation technique will be verified with the observation seismographs for Pidie Jaya earthquake M6.5 on 7 December 2016 from BMKG seismometer stations. BMKG has used the seismometers with type Trillium-120 (Nanometrics), BBVS-120 (Geodevices), and STS2. It is important to know the true instrumental response for applying the instrument correction and filtering the data at the adopted threshold of frequency used in the seismograms computation, before comparing the computed seismograms with the real recorded seismic data. The data of Pidie Jaya earthquake have been recorded and also available, as shown in Figure 3.

4. Comparison Synthetic and Observation Seismogram

Synthetic and field observations data are gotten from different sources. Synthetic data are gotten from simulation while observation data are gotten from field observation from BMKG station recording ground shaking when the earthquake occurs. Figure 3 shows the available data from six stations, whereas four stations have seismometer and accelerometer while another two stations have seismometer only. Due to the limitations in this writing, we only discuss several seismograms from two stations KCSI and LASI, as shown in Figure 4.

Figure 4a, 4c, and 4e show the seismograms recorded by the seismometer that measure velocity for the KCSI station. The waveform package between synthseses of simulation results 1 Hz (red) and 10 Hz (green) have similarities. Verification with observational data is compatible with its wave envelope especially for the horizontal components EW (east-west) and NS (north-south). The conformity of this maximum amplitude is very useful for validating the PGV (peak ground velocity).Waveform data for the LASI station (Figure 4b, 4d, and 4f) show that the compatibility between synthetic data with observations waveform is significantly different, relative to KCSI station. The waveform envelope of observation is larger than the waveform from synthetic seismogram and followed by the significant coda wave effect. This significant difference can happen because the LASI station is located in thicker sedimentary layer compared with the KCSI station which is located in a thinner sedimentary layer or bedrock area. The seismograms waveforms are more dispersed than those of synthetic seismograms because the synthetic seismograms are computed on a 1D rock structure without considering the scatter, site effect, and another factors.
Figure 4. The recorded seismograms are plotted with a gray line while the synthetic seismograms computed at 10Hz and 1Hz cutoff frequency are plotted with green and red lines, respectively. The left side are taken from the station KCSI (Kutacane) 3.522°N 97.772°E, with distance of 263 km, while the right side are taken from the station Langsa Aceh (LASI) 4.457°N 97.970°E, with epicenter distance of 219.78 km.

5. Conclusions and Suggestion
Modal summation technique has successfully generated synthetic seismogram and has adequate verification for waveform envelope with observational data from BMKG seismometer which is located on bedrock area. Considering phase wave, there is a slight difference between synthetic and observation. However, the verification of waveform envelope is sufficiently precise for NDSHA purpose which we concern on PGV. For regions which have significant thick sedimentary layer, the 1D model of summation technique must be consolidated with 2D finite different model so that the amplification effects can be taken into account. Research on the synthetic seismogram needs to be compared with other methods and developed in order to increase the precision of NDSHA map.
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