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Realistic Shakemap M6.5 Pidie Jaya Earthquake 7 December 2016 Based on Modal Summation Technique

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Realistic Shakemap M6.5 Pidie Jaya Earthquake 7 December 2016 Based on Modal Summation Technique

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Abstract. The shakemap were usually generated based on strong ground motion calculations on attenuation equations of the Ground Motion Prediction Equation (GMPE). However, the GMPE is a general equation which does not take into account the structural model of each layer of the subsurface. It considers only the structure of the surface layer known as Vs30 calculated as amplification in shakemap calculation. In this paper, the realistic calculation of shakemap for Pidie Jaya earthquake of 7 December 2016 with magnitude M6.5 is performed. Shakemap is generated from a number of synthetics seismogram calculations from source to site-based capital calculation summation Technique. Neo Deterministic Seismic Hazard Analysis (NDSHA) has included in the calculation of the synthetics seismograph. Before engaging the Vs30 effect, the realistic shakemap capable of producing effects of the angular distribution of a double-couple model in a realistic calculation. This could give an advantage of realistic shakemap while the GMPE based shakemap had not taken into account the double couple model. The realistic calculation of modal summation technique for shakemap can be further developed by involving local structural models in a more comprehensive manner.
Keywords: Shakemap, NDSHA, Pidie Jaya Earthquake

1. Introduction

Shakemap is very essential information for a quick post earthquake respond to the impact area. A global community respond, a shakemap for significant destructive earthquake usually released by USGS (US Geological Survey) [1]. Immediately, after Pidie Jaya earthquake 7 December 2016, USGS released shakemap as shown in figure 1.

A shakemap is a collection of PGA (peak ground acceleration) and PGV (peak ground velocity) parameter for whole coverage area with certain grid resolution. The parameters that been used for a shakemaps are estimated based on specific GMPE (Ground Motion Prediction Equation) and the whole task is managed by an integrated program ShakeMap[2][3]. Regarding the Pidie Jaya earthquake[4] with magnitude M6.5 and located at crust (focal depth 13 km). The GMPE from

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Zhao_crustal[5] were selected for the ShakeMap program. Therefore, the shakemap was the GMPE based shakemap or attenuation equation based shakemap. Prediction PGA and PGV from GMPE had a bias error because the equation ignoring the radiation pattern of focal mechanism and could not consider the completed structural model.

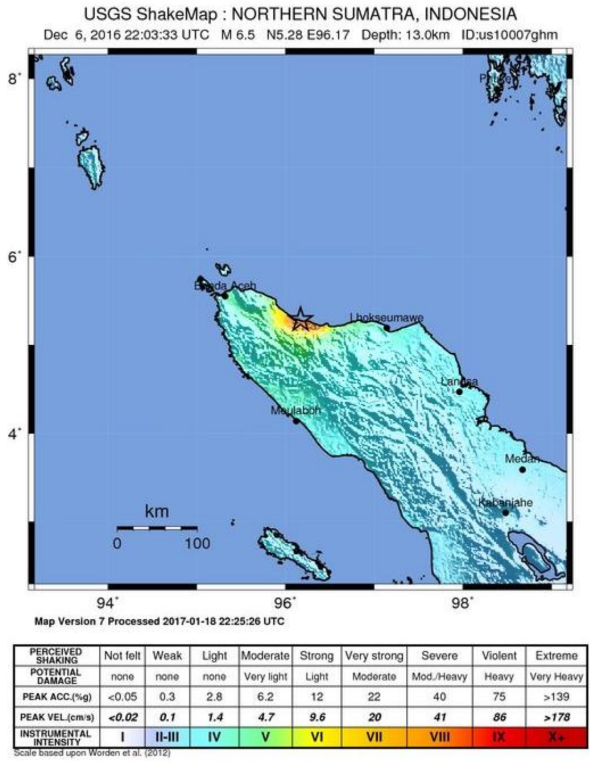


Figure 1. The standard shakemap released by USGS uses the Modified Mercalli Intensity (MMI) scale. The map show the scale and associate range of accelerometer and velocity[6]. USGS release the map extern area too large thus it cannot provide detailed information about the affected area.

The actual PGA and PGV were collected from the peak value of recording seismic seismogram or accelerometer waveform data from the field after removing the instrument respond effect. However, the seismic station could not cover the whole area, thus we had to collect the peak value from the synthetics seismogram. The algorithm to produce synthetics seismogram was developed by Panza[7] using modal summation method. The synthetics seismogram has adequate suitability with recoding seismogram [8] and accelerogram[9] from several Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG) stations during the Pidie Jaya earthquake. In addition, the synthetics response spectral had a good comparison with the recording waveform data[10]. Because of the accuracy of modal summation technique for producing synthetics seismogram, we produced more realistic shakemap based on the collected data of PGA and PGV from synthetics seismogram and compared them with the GMPE based shakemap that was produced by UGSG. The synthetics seismogram based shakemap for below discussion, we called as a realistic shakemap. The synthetic seismogram was intensively used in Neo Determinitic Seismic Hazard Analysis (NDSHA)[11].

2. Methodology

The computation cost for calculating PGA and PGV from GMPE was inexpensive and not time-consuming. The data later was used for producing high-resolution map thus the shakemap represent in continues data as shown in figure 1. However, the computation cost for getting PGA and PGV from synthetics seismogram was relatively expensive and taking a long time for computing a high-resolution map. Due to compatibility for comparison of both maps, a downsizing resolution of GMPE

shakemap to the resolution of shakemap from synthetics seismogram to the resolution of about 0.01 degree was considered. In addition, both of shakemap should be applied with the same color bar scale. The GMPE based shakemap was directly taken from USGS website for the ground motion on the rock with file data rock_grid.xml.zip. The XML format had to be converted to a standard column format which can read by GMT (Generic Mapping Tools) for plotting into the map as shown in figure 2. The ground motion on sediment layer (including amplification effect[12]) is provided in column format by USGS with file name grid.xyz.zip which can be plotted directly by GMT without any format conversion as shown in figure 3.
An advanced method for producing shakemap by estimating the PGA and PGV based on synthetics seismogram using modal summation technique[7]. The displacement can be expressesed in the asymptotic summation over mode index m, where each index expresses as:

$$
\begin{aligned}
{}^{m}U_x(r,z,\omega) &= \frac{e^{\frac{-3}{4}i\pi}}{\sqrt{2\pi}}\left[\chi_R(h_s,\varphi)S(\omega)\frac{\sqrt{k_R}e^{-ik_R r-\omega r C_{2R}}}{\sqrt{r}}\frac{\epsilon_0 u_x(z,\omega)}{2c_R v_{gR} I_{1R}}\right]_m \\
{}^{m}U_y(r,z,\omega) &= \frac{e^{\frac{-3}{4}i\pi}}{\sqrt{2\pi}}\left[\chi_L(h_s,\varphi)S(\omega)\frac{\sqrt{k_L}e^{-ik_L r-\omega r C_{2L}}}{\sqrt{r}}\frac{u_x(z,\omega)}{2c_L v_{gL} I_{1L}}\right]_m \\
{}^{m}U_z(r,z,\omega) &= {}^{m}U_x(r,z,\omega)\frac{e^{\frac{-i\pi}{2}}}{\epsilon_0}
\end{aligned}
\tag{1}
$$

The suffixes R and L is refered to the quantities that was associated with Rayleigh and Love modes, respectively. In Equation 1, $S(\omega) = |S(\omega)|\exp[i\cdot\arg(S(\omega))]$ is the Fourier transform of the source time function while $\chi(h_S,\varphi)$ represents the azimuthal dependence of the excitation factor expressed:

$$
\chi_R(h_s,\varphi) = d_0 + i\chi_L(h_s,\varphi) = i \tag{2}
$$

with:

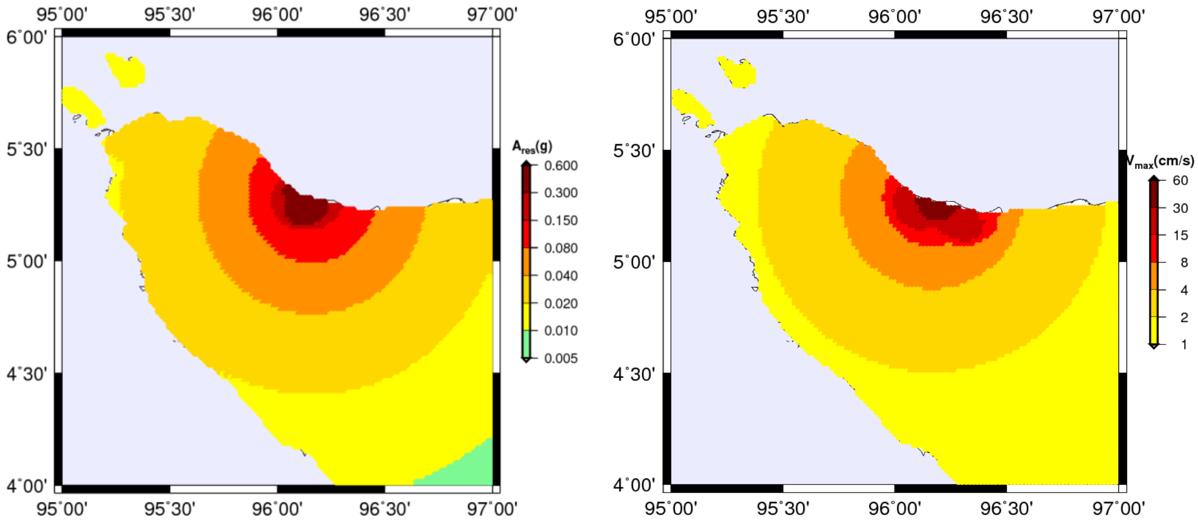
$$
\begin{aligned}
d_0 &= \frac{1}{2}B(h_s)sin\lambda sin2\delta & d_{1L} &= G(h_s)cos\lambda sin\delta \\
d_{1R} &= -C(h_s)sin\lambda cos2\delta & d_{2L} &= -G(h_s)sin\lambda cos2\delta \\
d_{2R} &= -C(h_s)cos\lambda cos\delta & d_{3L} &= \frac{1}{2}V(h_s)sin\lambda sin2\delta \\
d_{3R} &= A(h_s)cos\lambda sin\delta & d_{4L} &= V(h_s)cos\lambda sin\delta \\
d_{4R} &= \frac{-1}{2}A(h_s)sin\lambda sin2\delta & &
\end{aligned}
\tag{3}
$$

Where φ is the angle between the strike of the fault and the direction obtained for connecting the epicenter with the station which is measured anticlockwise; h_S is the focal depth; δ is the dip angle and λ is the rake angle. Detailed proofed of the equation could be seen in Panza[13]. Realistic shakemap could calculate PGA and PGV based on synthetic seismogram by using the above equation. The equation (2) and (3) shows the radiation pattern as the function of focal mechanism and be plotted in figure 3 and figure 4.

3. Results and Discussion

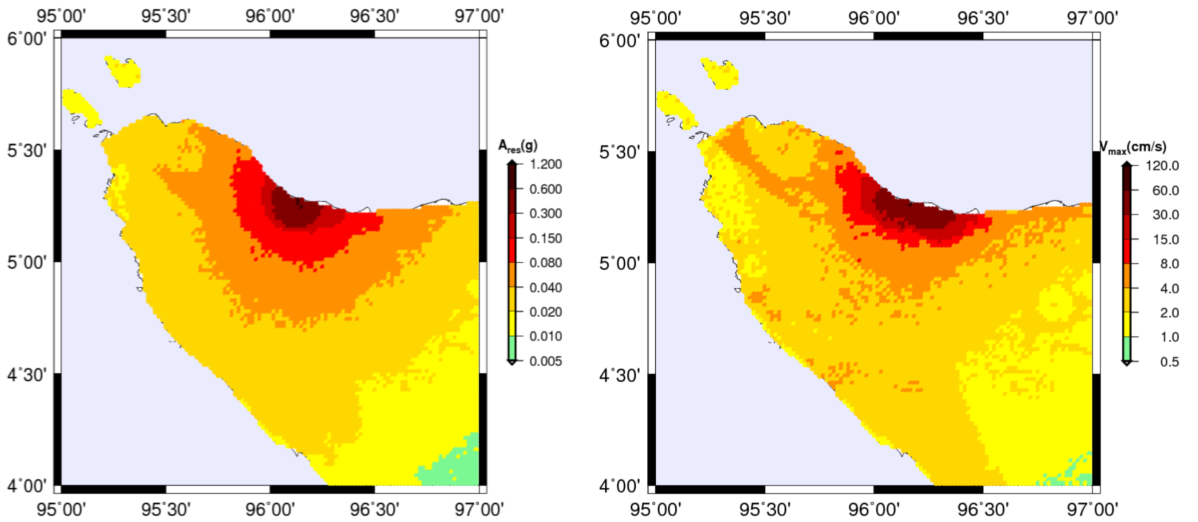
The shakemap on bedrock from USGS had not varyied for azimuthal angle and spherically symmetry as shown in figure 2. The procedure to generate strong ground motion parameter PGA and PGV based on GMPE was not the function of azimuthal angle. The equation that was used in GMPE had no capability to take into account the variation structural model bellow thin sediment layer (<30m).
Figure 3 shows the shakemap on the sedimentary layer in which the site amplification effect calculated independently from average shear velocity until deep to 30m. The spherical symmetry from figure 2 was disturbed by the site amplification effect. The location was identified by the sediment layer could

be amplified. The effect of amplification follows the path of the basin of Banda Aceh was shown in figure 3.



(a) PGA shakemap (a) PGV shakemap

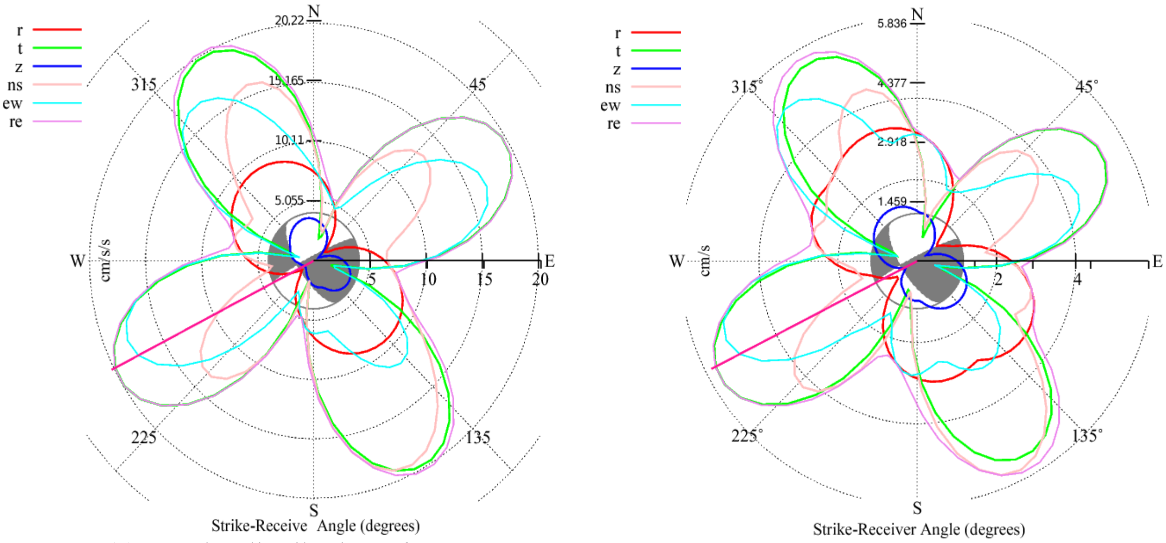
Figure 2. The GMPE based shakemap on the bed rock



(a) PGA shakemap (a) PGV shakemap

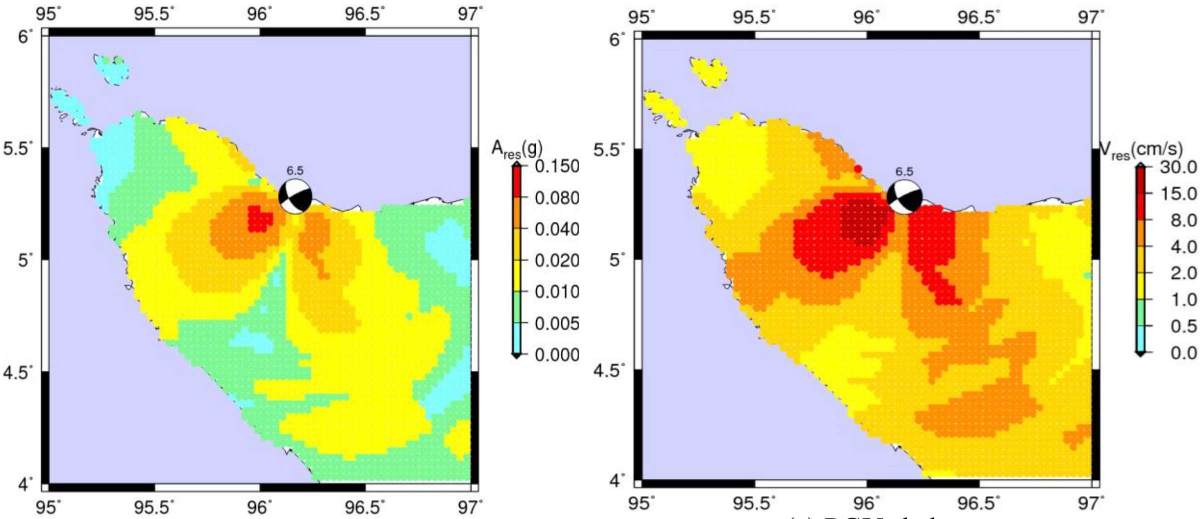
Figure 3. The GMPE shakemap on the sediment layer has include the amplification factor from V30.

However, the PGA and PGV from the synthetic seismogram included the radiation pattern of the focal mechanic that using double couple method. Figure 4 shows the radiation patterns for epicenter distance 50 km with the uniform structural model. The shakemap produced from synthetic seismogram followed the radiation pattern as shown in figure 5. The realistic shakemap had not yet included the amplification of the upper sedimentary layer, however, the deeper structure was considered by modal summation technique as appear the increasing PGA and PGV respect to distance for several locations.



(a) angular distribution of PGA (b) angular distribution of PGV

Figure 4. Radiation pattern of PGA and PGV based on modal summation synthetic seismogram for epicenter distance 50km



(a) PGA shakemap (a) PGV shakemap

Figure 5. The realistic shakemap on the bed rock is calculated PGA and PGV by modal summation technique

4. Conclusions and Suggestion

The GMPE based shakemap required relatively a cheap computation cost because it could calculated directly the PGA and PGV from the generic equation but sacrificed the bias error because the calculation was not including the radiation patterns and intermediate and deeper structural model. However, the GMPE based shakemap had included the top thin sediment layer amplification factor.

The realistic shakemap obtained the PGA and PGV from the realistic calculation of synthetic seismogram which involving the radiation patterns of focal mechanic and considering the completed structural model of bedrock. However, the realistic shakemap had not yet included the top thin sediment layer of the amplification factor. For future development, we suggest to elaborate the top thin sediment layer of the amplification factor (V30 based amplification) for a realistic shakemap computation.

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