Analysis on some strong ground motion records from the 2016 Kumamoto earthquake series

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Abstract. The 2016 Kumamoto earthquake sequence started with an M_{JMA} 6.5 earthquake in Kumamoto Prefecture on April 14, 2016, which is the foreshock. A larger earthquake of M_{JMA} 7.3 occurred on April 16, which is the mainshock. We analyzed the data of K-NET stations to get the distribution characteristics of PGA. The characteristics of foreshock and mainshock is a little different. This phenomenon may be caused by fault directivity effect. We selected strong motion recordings and calculated the curve based on the fourier amplitude H/V ratio method, then identified the predominant frequency to analyze the nonlinear site effect.

1. Introduction

Two strike-slip earthquake occurred on April 14 and 16, 2016 in Kumamoto Prefecture, and caused significant damage to the Kumamoto region. And then a series of aftershocks occurred in this region. We select the sequence to analyze, which is listed in Table 1.

| Date and Time       | Magnitude |
|---------------------|-----------|
| 14 April 2016 21:26 | 6.5       |
| 14 April 2016 22:07 | 5.8       |
| 15 April 2016 00:03 | 6.4       |
| 16 April 2016 01:25 | 7.3       |
| 16 April 2016 01:44 | 5.4       |
| 16 April 2016 01:46 | 5.9       |
| 16 April 2016 03:55 | 5.8       |
| 16 April 2016 09:48 | 5.4       |

The earthquake sequence occurred along the Futagawa fault zone and the northern part of the Hinagu fault zone in central Kyushu (Fig1). PGA is a very important parameter to show ground motion characteristics. Through a series of acceleration waveforms, we choose two K-NET stations (KMM006 and KMM009), which is shown as two triangles in Fig1, whose PGAs are larger than others.
2. Regional Ground Motion Characteristics

Through interpolating the PGAs of 370 K-NET stations and 328 KiK-net stations, whole PGA distribution is showed in Figure 2 and Figure 3. We choose the records from foreshock and mainshock to analyze [7].
It can be observed that PGA in near-field attenuates radically all around with ellipse shape \[^6\]. For the foreshock, in the EW components, the maximum values of PGA occurred at station KMM009 while in the NS components, the maximum values of PGA occurred at station KMM006. The rupture direction is not clear in Figure 2(a), however, in Figure 2(b), a peak value is found near the hypocenter, and another one is found at the southeastern of the hypocenter, which corresponds to the source rupture process of the foreshock (Asano and Iwata, 2016). For mainshock, in the EW components, the maximum value of PGA occurred at station KMM008 while in the NS components, the maximum value of PGA occurred at station KMM006. The rupture direction is clear in Figure 2(c) and 2(d), which corresponds to the source rupture process of the mainshock (Asano and Iwata, 2016).
For KiK-net stations, neither borehole or ground surface, PGA in near-field attenuates radically all around with ellipse shape, too. For foreshock, in the EW and NS components, the maximum value of PGA both occurred at station KMMH16. For mainshock, in the EW components, the maximum value of PGA occurred at station KMMH16 while in the NS components, for ground surface, the maximum value of PGA occurred at station KMMH03, for borehole, the maximum value of PGA occurred at station KMMH02. This phenomenon may be caused by fault directivity effect and near surface fault-downside fault effect [3].

3. The Nonlinear Site Effect
The H/V spectrum radio method can be used to analyze site characteristics [1], which is not restricted by the conditions of reference site, epicentral distance, etc [1]. The larger the H/V spectral ratio is, the more obvious the amplification of site soil is [4]. The peak value of spectral ratio is the maximum value of site amplification. The peak value appears at the predominant frequency of site soil generally. We choose the records of K-NET station KMM006[5]. And then analyses are conducted on the data. We use Butterworth filter for each record and select high pass cut-off frequency 0.1Hz and low pass cut-off frequency 30Hz [2]. H/V is calculated by Eq. (1). The horizontal Fourier spectrum use geometric mean of two horizontal components.
\[ \frac{H}{V} = \frac{\sqrt{EW \times NS}}{UD} \]  

where, UD is the vertical Fourier spectral amplitude, EW and NS are the horizontal Fourier spectral amplitudes.

The trend of predominant frequency changing can be analyzed by the HVSR curves of the whole sequence, which are shown as Figure 4.

Figure 4. the HVSR curve of KMM006
From the figure, after the first foreshock, the predominant frequency increases to round 3Hz, decreases to around 2Hz after the mainshock, and then decreases to around 1Hz during the last aftershock in Table 1. The nonlinear of site soil is observed in mainshock, to some extent.

4. Conclusion
In the 2016 Kumamoto earthquake sequence, fault directivity effect can be observed by N-S records from K-NET stations in foreshock, and can be observed by all records from KiK-net stations in mainshock. For foreshock, in the EW components, the maximum values of PGA occurred at station KMM009 while in the NS components, the maximum values of PGA occurred at station KMM006. For mainshock, in the EW components, the maximum values of PGA occurred at station KMM008 while in the NS components, the maximum values of PGA occurred at station KMM006. This phenomenon may be caused by fault directivity effect and near surface fault-downside fault effect. From the HVSR curve, the nonlinear response of the site of KMM006 station can be observed in mainshock.

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References
[1] Ji Kun. Research on site characteristics based on H/V spectral ratio method [D]. Institute of engineering mechanics, China Earthquake Administration, 2014
[2] Hu Jinjun. Research on directional effect and super shear rupture of near fault ground motion [D]. Institute of engineering mechanics, China Earthquake Administration, 2009
[3] Ji Kun, Wen Ruizhi, Ren Yefei, Wang Hongwei. Analysis of site characteristics based on Lushan aftershock strong vibration record [J]
[4] Kimiyuki Asano and Tomotaka Iwata, Source rupture processes of the foreshock and mainshock in the 2016 Kumamoto earthquake sequence estimated from the kinematic waveform inversion of strong motion dataEarth, Planets and Space (2016) 68:147
[5] Katsuichiro Goda, Grace Campbell, Laura Hulme, Bashar Ismael, Lin Ke, Rebekah Marsh, Peter Sammonds, Emily So, Yoshihiro Okumura, Nozar Kishi, Maki Koyama, Saki Yotsui, Junji Kiyono, Shuanglan Wu and Sean Wilkinson, The 2016 Kumamoto earthquakes: cascading geological hazards and compounding risks, frontiers in Built Environment(2016.00019)
[6] Seiji Tsuno, Masahiro Korenaga, Kazunori Wada and Kimitoshi Sakai. Characteristics of earthquake ground motions in the Kumamoto City, using the aftershock observation data of the 2016 Kumamoto Earthquake, Japan Geoscience Union Meeting 2016
[7] Z.C. LI & X.L. CHEN & M.T. GAO, H. JIANG, Simulation Near-field Ground Motion in Kumamoto Earthquake, Japan Mjma7.3 by Empirical Green Function Method, 5th International Conference on Civil, Architectural and Hydraulic Engineering (ICCAHE 2016)
[8] The 2016 Kumamoto Earthquake Portal. http://www.jma.go.jp/jma/en/2016_Kumamoto_Earthquake/2016_Kumamoto_Earthquake.html.