Characteristics of ground motion parameters in the 2008 Ms 8.0 Wenchuan earthquake

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SUMMARY:
The near field earthquake ground motions and engineering damage distribution caused by the great 2008 Ms 8.0 Sichuan Wenchuan earthquake was investigated to identify the rupture directivity effect. Statistical result indicates that this thrust faulting earthquake, dominated by the unilateral rupture propagation, caused a distinct rupture directivity effect on the ground motion recordings. Specifically, acceleration in forward direction is larger than that of the backward direction, and the difference depends on the rupture distance to the fault; response spectra in the forward direction is higher than that of the backward direction, especially for longer natural period; the difference between the forward and backward direction may reach 2~4 times on average.

Keywords: Wenchuan earthquake, ground motion parameter, directivity, engineering damage

1. THE GREAT WENCHUAN EARTHQUAKE

On May 12, 2008, a great earthquake of magnitude Ms 8.0 occurred in Sichuan province, China. The epicenter located (N31.0N, 103.4E) in Wenchuan county, which is only 21 km to Dujingyan city and 75 km to the provincial capital Chendu. This earthquake caused severe engineering damage with huge economic loss and death toll. The earthquake affected an extensive area of places, including Sichuan, Gansu, Shanxi, Chongqing, Yunnan and Ningxia. It also caused a large number of land slids and quake-lakes. The seismic intensity in the epicenter region reaches XI degree. Inversion of fault mechanics and field survey show that the rupture nucleated in Yingxiu town, then propagated to the north east direction. The whole fault is about 300 km from south west to north east, which is predominately a unilateral rupture thus it may cause a directivity effect both in the ground motion distribution and engineering damage (Hu, 2009).

Directivity caused by the rupture propagation effect is an important factor which both affects the distribution and attenuation of near-field ground motions and the low frequency wave forms (Somerville and Seism, 1996; Somerville, et al., 1997; Somerville, 2002; Abrahamson and Silva, 1996). This kind of effect is becoming more and more obvious in the near-field ground motions from the recent large earthquakes. The first study on ground motion directivity was carried out by Benioff in 1955, who studied the long period displacement ground motions in the Mw 7.5 Kern County earthquake. While the directivity effect in short period ground motions was not proved until 1978 by Bakun who studied two small earthquakes in middle California, this is more interesting to engineers. After that, with the development of strong motion observation technology, more and more near-field ground motion are provided for studying the directivity effect (Boatwright and Boore, 1982; Archuleta, 1982).

2. GROUND MOTION DATABASE

The 2008 Ms 8.0 great earthquake caused huge damage, it is one of the most destructive earthquakes in China. Strong motion instruments installed in the earthquake fault region recorded amount of near-field ground motions during the main shock. The China Strong Ground Motion Network Center acquired 420 sets of three-component acceleration recordings, which include free field, topographical and structural array stations. Thus it provides a good chance to study the characteristics of the ground motion distributions in the near-field region (Hu, 2009; Li, et al., 2008; Yu, et al., 2009).

We selected 198 sets of near-field acceleration ground motions from the released database. In order to analysis the directivity effect, we avoid the low signal-noise ratio or component-lost or too large rupture distanced recordings. And all the selected stations are on the similar soil site conditions. Figure 1 shows the ground motion stations and fault model. To compare the ground motions in different directions, we classify the stations into two types: stations which located in the forward direction is defined as the Forward Direction (FD) stations (shown as triangular in Figure 1); stations which located in the backward direction is defined as the Backward Direction (BD) stations (shown as circle in Figure 1). So there are 105 stations in FD and 93 stations in BD. Also, to analysis the directivity effect, the original orientated recordings were rotated to Fault Normal (FN) and Fault Parallel (FP) directions.

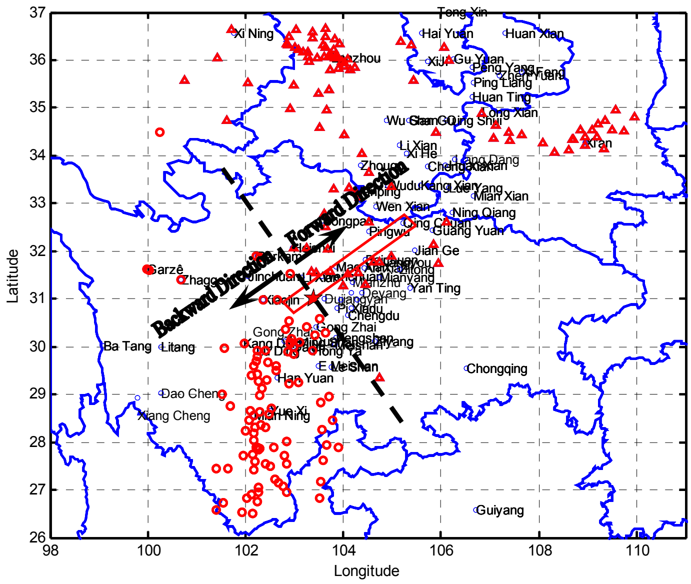


Figure 1. Strong ground motion stations in Wenchuan Earthquake

3. CHARACTERISTICS OF AMPLITUDE, SPECTRA AND DURATION

3.1. Peak Ground Acceleration Field

The Peak Ground Acceleration (PGA) is one of the most important parameters in characterizing a ground motion. We compare the contour maps and attenuation relations to see how the rupture directivity affects the amplitude distribution and the difference between the FD and FD. Based on the PGAs in all the selected locations, the PGA contour maps were obtained through a two dimensional interpolation method (see Fig. 2).

Figure 2 (a), (b) and (c) show the PGA contour maps of FN, FP and vertical component, respectively. Also, in the figures we draw a simple inverted finite fault model. From the contour map we can see that there exists a distinct difference between the FD and BD directions. In other word, the distribution of ground motion amplitude is affected by the rupture propagation direction. Results indicate that: on the one hand, for the similar rupture distance, the amplitude value in the rupture propagation direction (FD) is larger than that of the opposite direction (BD); on the other hand, the attenuation in the FD is slower than that of the BD, which is indicated from the contour intervals.

3.2. Peak Ground Acceleration Attenuation Relations

The quantitative analysis of FD and BD PGA attenuation relations is done through a simple amplitude-distance regression model (see Eqn. 3.1). In Eqn. 3.1, the distance is defined as the closest distance to the fault. Table. 1 is the three regression parameters a, b and c.

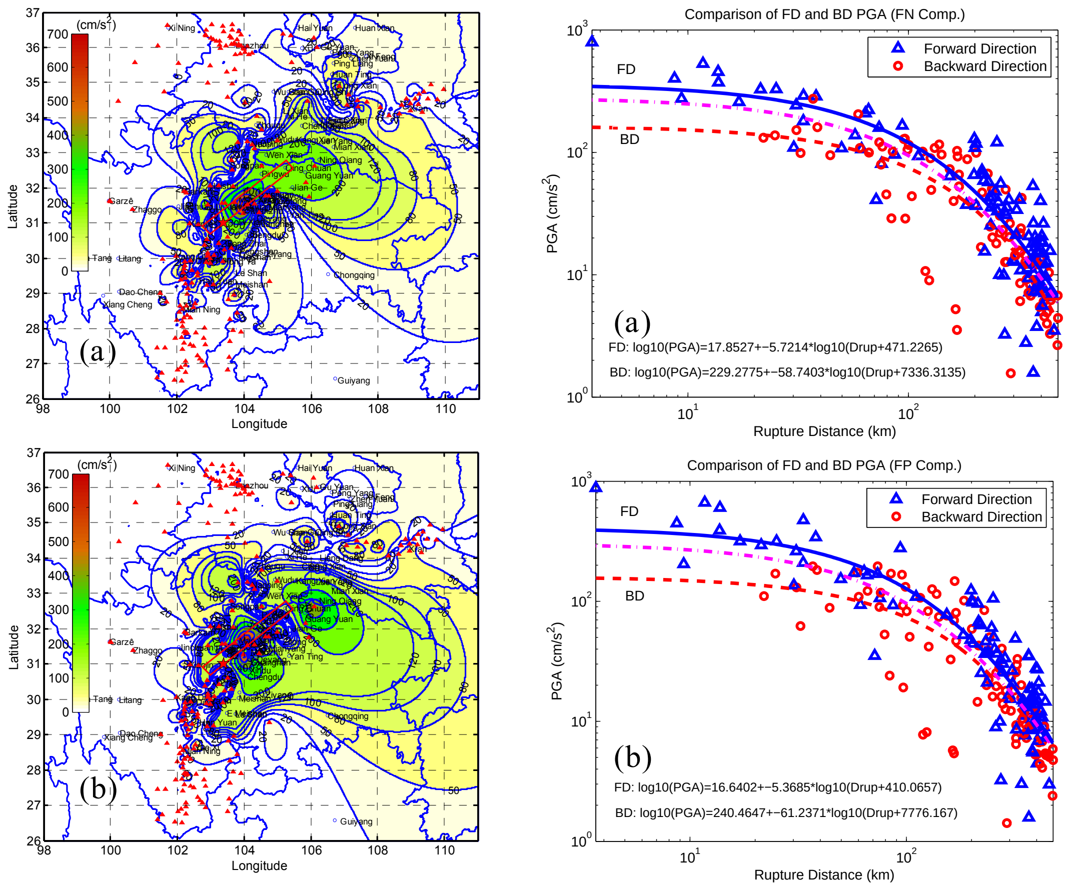
$$\log_{10}(PGA) = a + b * \log_{10}(D_{rup} + c) \tag{3.1}$$

Figure 3 shows the comparison of PGA attenuation relations in FD and BD. Where (a), (b) and (c) is the FN, FP and Vertical component, respectively. We give the FD, BD and all station regression model parameters and the attenuation relations. In Fig. 3, the blue solid line represents the FD attenuation relation; the red dash line represents the BD attenuation relation; the pink dot dash line represents the attenuation relation from all the FD and BD station data.

Table 3.1. PGA attenuation relation model parameters

Component	a	b	c
FN	15.4193	4.9712	406.6065
FP	13.7855	4.4684	338.7368
Vertical	6.0348	-1.9848	59.6074

From the comparison of the attenuation relation in FD and BD we can see that: on the one hand, for the same rupture distance, the PGA value in FD is larger than that of the BD; on the other hand, with the increasing of the rupture distance, the difference between the FD and BD is decreasing.



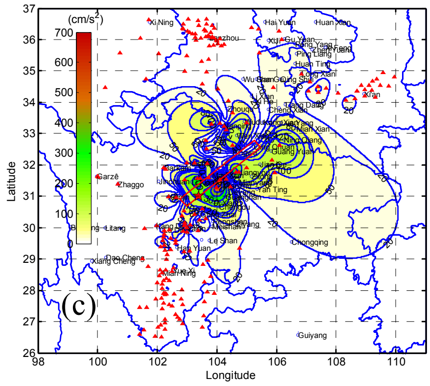


Figure 2. PGA contour map. (a) FN component;(b) FP component; (c) Vertical component

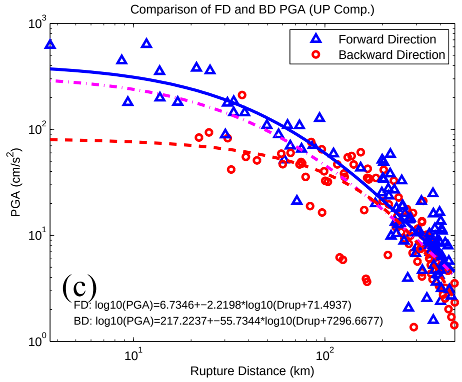


Figure 3. PGA attenuation relation in FD and BD. (a) FN component; (b) FP component; (c) Vertical component

3.3. Spectral Ordinate

The influence of directivity effect on spectral ordinate of ground motion is analyzed through the comparing the mean spectra of rupture forward and backward sites. Spectrum and mean spectrum of forward and backward sites and their ratio (FD-BD Ratio) are shown in Figure 4. It is observed that , for period shorter than 2sec, the mean spectra of forward sites (blue solid line) is about twice as large as that of backward (black dot and dash line); at long period (T>2sec), directivity effect is more significant and the spectral ratio can reach up to 4. This means the impact of directivity effect on structure with long natural period will be even more significant.

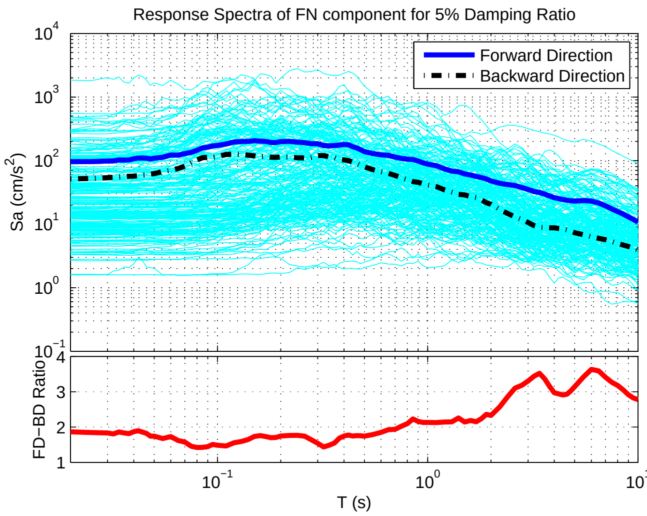


Figure 4. Mean spectra and its ration in forward and back word direction (FN component)

3.4. Energy Duration

The influence of directivity effect on the relative energy duration is present in this section. To compare the distance dependence of the duration for the backward and forward ground motion, a simple duration-distance attenuation relationship is chosen, described by Equation 3.2. The duration-distance distribution for the forward and backward is shown in Figure 5, along with duration-distance distribution based on the model obtained by Equation 3.2 at all sites including backward and forward. The regressed line for forward is represented with blue solid line, the one for backward and all sites are shown with red dotted line and pink dot dash line respectively, triangle and circle are the indicator for sites of the forward and backward .According to the figure, the duration for backward is markedly larger than forward, and the duration becomes longer with increasing distance.

$$T_{0.9} = a + b \cdot D_{rup} \tag{3.2}$$

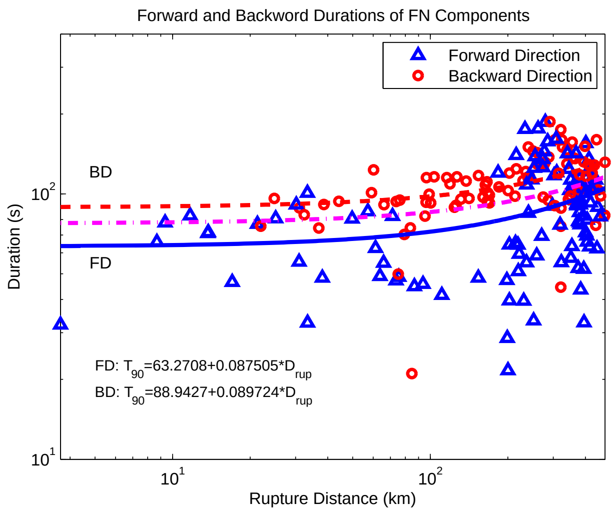


Figure 5. Relations between duration and distance

4. CONCLUSION

Through the selected 198 sets of three-component strong ground motions, we investigated the amplitude contour maps and attenuation relations of PGA, as well as the spectral ordinate and energy duration in the great Wenchuan earthquake to investigate parameters of ground motion between FD and BD. Results indicate that PGA is affected by the rupture directivity, both the ground motion field and attenuation relation show distinct difference between FD and BD: the amplitude is larger in the FD direction than that of the BD within the same rupture distance; and the difference decreases with the increasing of the rupture distance. Response spectra in the forward direction are higher than that of the backward direction, especially for longer natural period; the difference between the forward and backward direction may reach 2~4 times on average; the duration for backward is markedly larger than forward, and the duration becomes longer with increasing distance.

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