The ground motion simulation of Kangding Mw6.0,2014 by the stochastic finite-fault model

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Abstract. The November 22, 2014, Kangding strike-slip earthquake (Mw 6.0) occurred on the Southern Section of the Xianshuihe Fault Zone. Its epicenter was at 101.69°E, 30.26°N, source mechanism strikes N33°E, dips 82°, and slipped at an angle of –9°. In this work, we simulated ground motions by the stochastic finite-fault model (SFFM), including peak ground acceleration, peak velocity, and acceleration time-histories caused by this earthquake.

1. Introduction
The Xianshuihe Fault Zone is one of the most active fault zones in Southwest China, consisting of left-lateral, steeply dipping (70 to 80°), northeast-striking, segmented strike-slip faults. The Xianshuihe Fault Zone and the Ganzi-Yushu Fault together constitute the boundary between the Sichuan-Yunnan and Bayan Har crustal blocks, and undergo left-lateral strike-slip motion under a north–northeast-oriented regional maximum horizontal compressive stress (Fig. 1). More than eight strong earthquakes with magnitude greater than Mw6.0 have occurred in the Xianshuihe Fault Zone since 1893.

Figure 1. Active faults in the Xianshuihe Fault Zone and locations of magnitude Mw6.0 and greater earthquakes since 1893.
Thus, the region proximal to the Xianshuihe Fault Zone faces significant seismic hazard. More than 160,000 people live in towns and villages in the deep valleys, which are susceptible to landslides and rockfalls. The 2014 Kangding earthquake (Mw 6.0), the latest severe earthquake, killed five people, injured 80, and caused an estimated $1.6 billion in losses. Thus, appropriate mitigation measures to reduce seismic risk in the Xianshuihe Fault Zone are necessary, and they depend on a better ground-motion hazard assessment for the Xianshuihe Fault Zone. In this paper, we employ the stochastic finite-fault model to simulate the near-field ground-motion caused by Kangding earthquake, compared with strong motion recordings and isoseismic map.

2. The proposed method
The stochastic finite-fault model (SFFM) is a useful tool for predicting ground motion for large earthquakes [1,2] and has been used in a variety of studies and tectonic environments in California, eastern North America, Mexico, the Cascadia region, Greece, Russia, Italy, and China. SFFM simulates ground motions for large earthquakes by partitioning a large fault rupture into several sub fault ruptures, where each is considered as a small point source [3] and the rupture spreads from the hypocentre. The ground motions from ruptures of the sub faults, each of which is calculated by the stochastic point-source method, are summed with a time delay in the time domain to obtain the ground-motion acceleration, from the entire fault.

3. Evaluation process
we simulated ground motions, including peak ground acceleration, peak velocity, and acceleration time-histories, from the 2014 Kangding earthquake (Mw 6.0) at up to 3,048 grid points. The empirical relationships developed by the China Earthquake Administration [4] were used to convert the simulated PGAs and PGVs into instrumental intensities. The converted intensities were then used to construct an intensity distribution map and compared with the observed intensity distribution. The simulated acceleration time histories, peak ground-motion values, Fourier amplitudes, and response spectra were also compared with ground motions and spectral values recorded at several strong-motion stations from the 2014 Kangding earthquake.

The November 22, 2014, Kangding strike-slip earthquake (Mw 6.0) occurred on the Selaha-Kangding fault segment; epicenter was 101.69°E, 30.26°N. The source mechanism strikes N33°E, dips 82°, and slipped at an angle of −9°. Its focal mechanism has nearly horizontal principal stress axes striking at 99° and 189° for the compression (P) and tension (T) axes, respectively. The size of fault plane and rupture direction has an important influence on the distribution of the ground motions. The relocated aftershocks were used to determine the extent of the fault plane. Aftershocks that occurred within 90 days following the mainshock with magnitudes greater than 0.8 were relocated using the double difference relative-relocation algorithm, hypoDD [5], using the 1-D crustal velocity model developed for the Kangding area. The results showed that the aftershock distribution strikes northwest, consistent with surface rupture, and the rupture plane size is 15km wide and 30km long with a dip angle of 82°. The initial rupture propagated bilaterally to the northwest and southeast from the hypocenter, until encountering barriers at both ends (Fig. 2).
Using the source parameters (Fig. 2, Table 2), we simulated the ground motions on rock of $V_{30} \geq 618$ m/s for the Kangding earthquake using SFFM. First, we compared the simulated acceleration time histories, peak values, and spectra with the observed ones. Twenty-one strong-motion stations recorded the Kangding earthquake, and five of them were within an 80 km rupture distance. Table 3 lists the observed PGAs and simulated PGAs at five strong-motion stations within an 80 km rupture distance. Figure 3 compares the observed time histories and response and Fourier spectra with simulated ones at stations 51KDX, 51KDG, and 51KDT. As shown in Table 3 and Figure 3, the simulated time histories, response spectra, and Fourier spectra are quite close to the observed ones. Figure 4 compares simulated intensity contours and observed intensity distribution for the Kangding earthquake. As shown in Figure 4, the simulated intensity distribution is quite coincide with the observed intensity distribution, especially for intensities VII and VIII. These comparisons demonstrate that the source parameters and SFFM can be used for simulating ground motions from earthquakes in the Xianshuihe Fault Zone.
**Table 1.** Parameters of the stochastic finite fault model for the Kangding earthquake (Mw 6.0).

| parameter | value | parameter | value |
|-----------|-------|-----------|-------|
| strike/dip | 325°/82° | crustal density (g·cm⁻³) | 2.7 |
| fault dimension along strike and dip (km) | 30, 15 | shear-wave velocity (km/s) | 3.8 |
| sub fault dimensions along strike and dip (km) | 2, 1.5 | depth of the upper edge of the fault (km) | 2 |
| fault upper corner location | 39.43°N, 118.01°E | windowing function | Saragoni-Hart |
| moment magnitude | 6.0 | site amplification | Boore-Joyner general rock sites model [6] |
| Stress drop (bars) | 50 | quality factor Q (f) | 202 f⁰.⁷ |
| pulsing percent | 50 | rupture velocity | 0.8×shear wave velocity |
| distance dependent duration | 0 (R<10 km) 0.16R (10<R<70km) 0.03R (70<R<130km) 0.04R (R>130km) | geometrical attenuation | 1/R (R≤70km) 1/R⁰ (70<R≤130km) 1/R⁰.⁵ (R>130km) |

**Table 2.** Simulated and observed PGAs at five stations from the Kangding earthquake.

| INDEX | Name  | Long. | Lat. | Rrup (km) | Observed PGA (cm/s²) | Simulated PGA (cm/s²) |
|-------|-------|-------|------|----------|----------------------|-----------------------|
|       |       |       |      |          | EW | NS | UD |          |          |          |
| 1     | 51KDX | 101.50| 30.04| 33.4     | 150.87 | 161.75 | 174.00 | 157.49 |
| 2     | 51KDG | 101.57| 29.96| 37.1     | -153.76 | -154.39 | 117.60 | 144.92 |
| 3     | 51KDT | 101.96| 30.05| 36.7     | 104.38 | 134.16 | -72.97 | 138.11 |
| 4     | 51LDS | 102.23| 29.91| 65.0     | -24.60 | -46.14 | 24.54  | 46.89  |
| 5     | 51TQL | 102.39| 29.93| 76.7     | 36.77  | 33.58  | -12.63 | 35.49  |

![Graphs](image-url)
Figure 3. Comparison of observed and simulated acceleration time-histories (a), response spectra with 5 percent damping (b), and Fourier spectra (c) at stations 51KDX (top), 51KDG (middle), and 51KDT (bottom).

Figure 4. Isoseismic contours from observed peak ground accelerations and velocities (black) and SFFM simulations (green). Near-fault strong-motion stations, at which observed time-histories were modeled, are shown as inverted blue triangles.

4. Discussion
The Xianshuihe Fault Zone is very active and poses significant hazard to communities in the area. Thus, it is vitally important to develop appropriate ground-motion hazard maps for engineering design and other mitigation for the area. Although PSHA has been used to develop ground-motion hazard maps in China, recent studies have shown that PSHA is scientifically flawed [7]. Thus, the use of PSHA has led to earthquakes in China such as the 2008 Wenchuan and 2010 Yushu being disastrous.

As demonstrated in this paper, scenario-based seismic hazard analysis is based on observations and well-known seismological relationships such as fault rupture dimension and the magnitude relationship of Wells and Coppersmith [8]. Thus, the results have a sound physics base and can be easily tested. For example, the scenario-based hazard map can be directly compared with historical and future earthquakes in the Xianshuihe Fault Zone. Another advantage of scenario-based hazard analysis is that it can provide ground-motion time histories, which are important for engineering analysis and other applications.
5. Conclusion
The Xianshuihe Fault Zone is seismically very active and of characteristic behaviour. We performed ground-motion simulation of Kangding Mw6.0,2014 that utilizes observations and well-known seismological relationships. The results have a sound physics base and can be easily tested. For example, the scenario-based ground-motion hazard maps can be directly compared with historical and future earthquakes in the Xianshuihe Fault Zone. Scenario-based seismic hazard analysis also has other advantages, such as being easy to understand and use.

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