16th World Conference on Earthquake Engineering, 16WCEE 2017

Santiago Chile, January 9th to 13th 2017

Paper N: 3121

Registration Code: S-O1465761912

SIMULATION ON NEAR-FIELD HIGH-FREQUENCY, FAR-FIELD ABNORMAL INTENSITY GROUND MOTIONS OF M_S8.0 WENCHUAN EARTHQUAKE BY EMPIRICAL GREEN FUNCTION METHOD

X. L. Chen(1), Z. C. Li(1), M. T. Gao(1), T. F. Li(1), J. P. Guo(1) and Q. F. Li(1)

(1) *Division of Engineering Seismology and Urban Disaster Mitigation, Institute of Geophysics, China Earthquake Administration, Beijing 100081 chenxueliang007@126.com*

Abstract

To further study the ground motion characteristics in the near-filed and far-field abnormal intensity ground motions of 2008 Ms8.0 Wenchuan earthquake, we simulated this giant event by empirical green function method. First, we chose 7 strong earthquake stations in which epicenter distance is less than 80km. The simulated results showed that, the time-histories records of high amplitude acceleration section are similar between observed values and synthetic values. Synthetic PGA is fitting better with observed PGA at the whole stations while synthetic PGA is a bit smaller than observed PGA in complicated terrain regions. This may be caused by terrains and site conditions in this area.

The old Hanyuan county town far away from the epicenter suffered serious damage during Wenchuan earthquake. It is the only abnormal intensity VIII region in intensity VI region. Based on the Hanyuan strong motion investigation, the damage situation was introduced, and the data on strong ground motion and soil site conditions were collected. We chose 3 stations near the Hanyuan county for studying the characteristic of abnormal intensity region. The Hanyuan county town is far away from the epicenter suffered serious damage probable caused by complex source rupture process characteristic, the propagation medium, field environment and topographic effects. At last, we also discussed the principles of how to choose small aftershocks as green function. Because the source rupture progress of Wenchuan earthquake is too complicated, simulation results still have room for improvement.

Keywords: Simulation, Empirical green function, Hanyuan County, Abnormal intensity, Wenchuan earthquake.

Introduction

Wenchuan earthquake (Ms8.0) occurred on May 12, 2008 in LONGMEN-mountain which located in the juncture between Sichuan basin and Tibetan Plateau. Its source location is (31.44N，104.10E) while depth is 12.8km [26, 27]. It caused very serious damage in southwest of china. About 70 thousand people died in this large catastrophe. Most damage happened in the near-field. So if we study well the near-field ground motion, it will be very useful for disaster prevention and earthquake resistant design. Using simulated results, we can also provide earthquake engineers, emergency response personnel and other government and private official with ground motion estimates that will allow them to take the appropriate action [12-25].

Ground motion is a complicated phenomenon. There are so many important factors which we still can't accurately estimate, such as different dynamic process, fissure structure in hypo-center and propagation process, which can produce many uncertainty changes. Because of the great development of strong earthquake observation, people's recognition about ground motion caused by earthquake is promoted a lot. Near-field strong ground motion has become an important domain in seismology and earthquake engineering in these years. So it is very significant and imperative to study the characteristics of near-field strong ground motion. Many predecessors have conducted a lot of research about synthetic strong ground motion [16-20].

In this study, we used empirical green function method, which was revised by Irikura, to simulate Wenchuan Earthquake. The basic thought of EGFM [1,2,6]: Supposing main earthquake hypo-center consisted of many elements earthquake hypo-centers. Choosing an appropriate small earthquake as the ground response caused by a point source, where the small earthquake is regarded as empirical green function. Superposition these empirical green function composes the main earthquake time histories according to a sort of rupture pattern [11]. Because the small earthquake record has contained influences of propagation path, so simulation process has considered the complexity of propagation medium and overcome the difficulty of theoretical green functions.

We chose 7 strong earthquake stations in which epicenter distance is less than 80km. These stations are all locating in the near fields. These near-field stations could reflect the characteristic of Wenchuan earthquake. We also chose 3 strong earthquake stations near the Hanyuan-county for studying the characteristic of abnormal intensity region. The Hanyuan county town is far away from the epicenter suffering serious damage during Wenchuan earthquake. It is the only abnormal intensity VIII region in intensity VI region.

2. Earthquake data

Wenchuan earthquake (Ms8.0) occurred on May 12, 2008, in Longmen-mountain, which located in the juncture between SICHUAN basin and Tibetan Plateau [26, 27]. Its source location is (31.44N, 104.1E) while depth is 12.8km. The magnitude of small earthquake is Ms5.8. The distance between their epicenters is about 4km. Data for this study are provided by China Strong Motion Network Center at Institute of Engineering Mechanics, China Earthquake Administration. We chose 7 stations which their epicenter distance was less than 80km shown in Fig.1. All those stations' site condition is soil. The average altitude of this region is about 3000m.

For studying the characteristic of Hanyuan abnormal intensity region, we chose a small earthquake (Ms5.0) which was relatively closed to Hanyuan-county. Its source location is (30.29N, 103.29E) while depth is 22.7km (Fig.1). The distance between Hanyuan county and epicenter of Wenchuan is about 267km. The acceleration of former aftershock (Ms5.8) becomes very small near Hanyuan-county. The sign-to-noise ratio is also very lower at stations near Hanyuan-county. So we change another small earthquake as green function to simulate ground motion of Hanyuan-county.

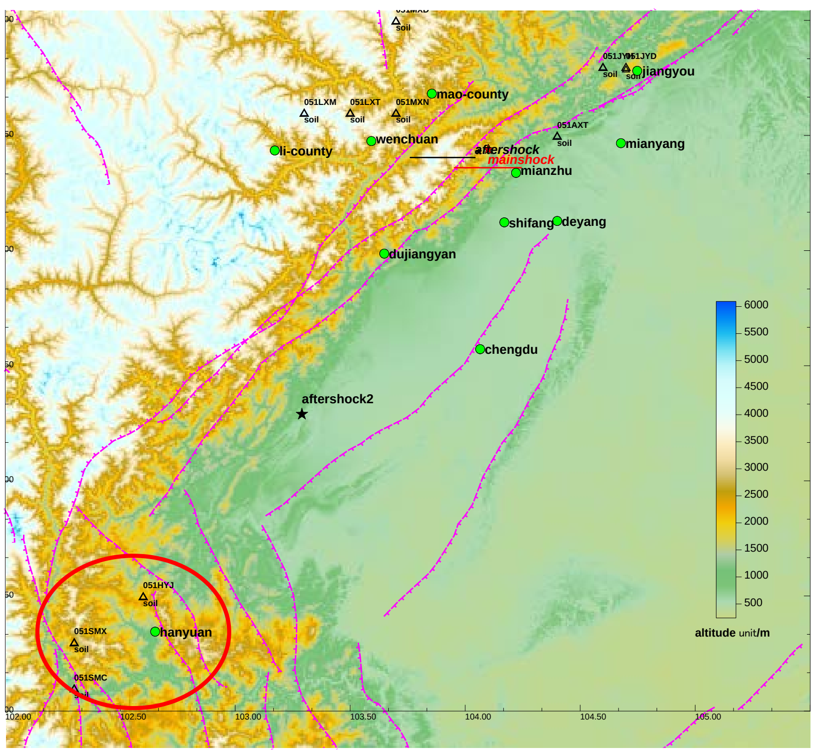


Fig.1 Information about Wenchuan earthquake. Pink disconnection line means faults. Red-line circle means abnormal intensity region. Aftershock2 means another green function for simulating ground motion of Hanyuan abnormal intensity region.

3 Simulation process

Using Irikura and Hiroe Miyake's method[1][2][6], we chose two aftershocks as empirical green function which magnitude were Ms5.8 and Ms5.0. Choosing Ms5.8 as empirical green function, which is because it have about the same epicenter and better similar focal mechanism with main-shock. Focal mechanism is also one precondition of choosing small earthquake. Choosing Ms5.0 as empirical green function, which is because it have better quality earthquake data and high sign-to-noise ratio through its hypo-central distance is a little larger. Using SeismoSignal software analyzes the earthquake records both observed data and synthetic data. Here, we mainly analyzed time-histories and PGA. More source parameters' information about earthquakes is offered in Table1.

Table 1 The relevant parameters of two earthquakes

	Magni tude	Latitude	Longitude	Strike angles	Dip angles	Rake angles	Depth	Rupture Velocity	S-wave Velocity
Main shock	M_S8.0	31.44N	104.1E	231°	35°	138°	12.8km	2.8km/s	3.1km/s
after shock1	M_S5.8	31.43N	104.06E	213°	42°	109°	14.0km	2.8km/s	3.1km/s
after shock2	M_S5.0	30.29N	103.29E	234°	48°	119°	22.7km	2.8km/s	3.1km/s

Equation for synthetiszed main-shock by aftershock[1][2]:

$$U_0(x,t)=\sum_{i=1}^{N_l}\sum_{j=1}^{N_w}\sum_{k=1}^{N_d}\frac{R_{ij}(\theta,\phi)}{R_s(\theta,\phi)}\cdot\frac{r_s}{r_{ij}}\cdot u_s(t-t_{ijk}) \qquad (1)$$

Where $U_0(x,t)$ is synthetic main-shock record; $u_s(t-t_{ijk})$ is aftershock record; $R_{ij}(\theta,\phi)$ and $R_s(\theta,\phi)$ are radiation factors of element earthquake and aftershock, respectively; r_{ij} and r_s are hypo-central distance of element earthquake and aftershock, respectively; t_{ijk} is the element earthquake rupturing time: $t_{ijk}=t_{ijr}+t_{ijc}+t_{ijd}$, $t_{ijr}=\left|\xi_0-\xi_{ij}\right|/V_r$, $t_{ijr}=\left|R_s-R_{ij}\right|/V_c$, $t_{ijd}=(k-1)\tau_s$. t_{ijr} , t_{ijc} , t_{ijd} means element source rupturing time, propagation lag time and dislocation process lag time, respectively; ξ_0 is the coordinate of first rupturing location while ξ_{ij} is the coordinate of (i, j) element source. The program used for simulation, which is revised by Prof. Hiroe Miyake. First export data of program, which are waveform data and frequency spectrum data. In this part, according to export result, we compared and analyzed time-histories and PGA between the observed values and the synthetic values.

4 Time-histories, PGA comparison and analysis

4.1 Result of near-field ground motion

In this study, we chose 7 strong earthquake stations' data for simulation. These stations had recorded the earthquake record both main-shock and aftershock. Because of paper length limit, only three stations' simulated results were listed in this section. The simulated results were shown in Fig.2, Fig.3 and Fig.4.

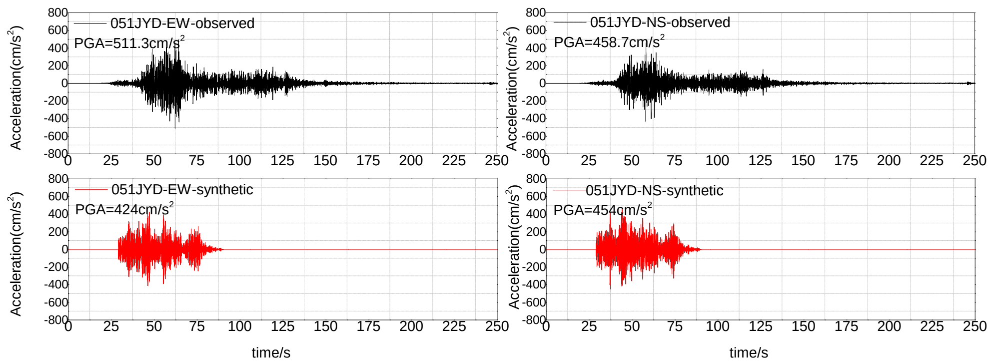


Fig.2 Simulation and comparison of Station 051JYD, Upper figures (black) means observed data while below figures (red) means synthetic data.

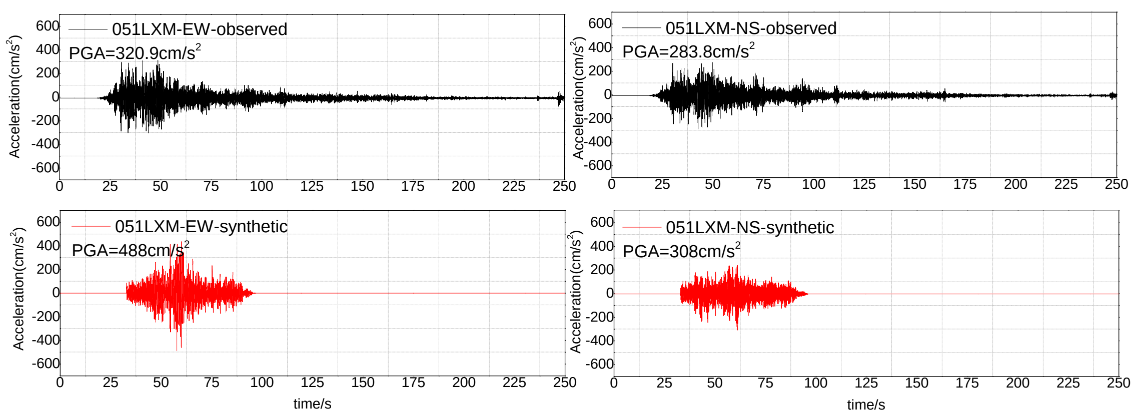


Fig.3 Simulation and comparison of Station 051LXM, Upper figures (black) means observed data while below figures (red) means synthetic data.

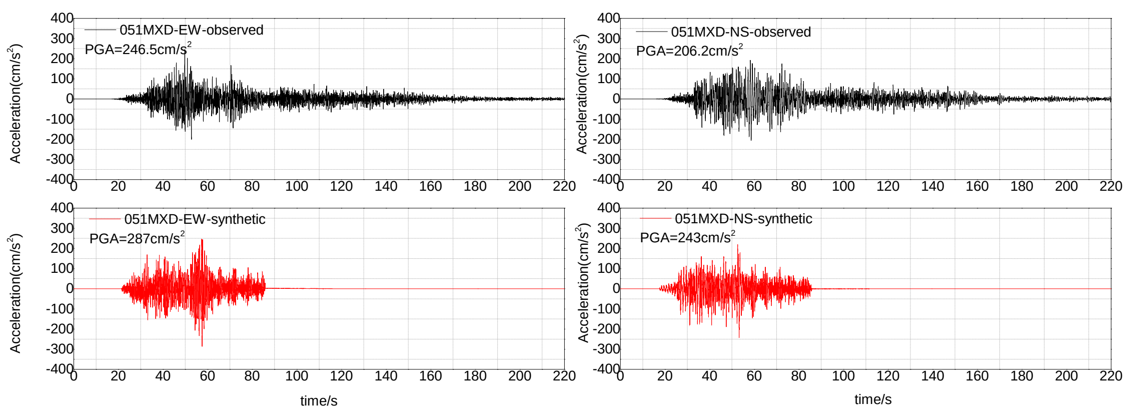
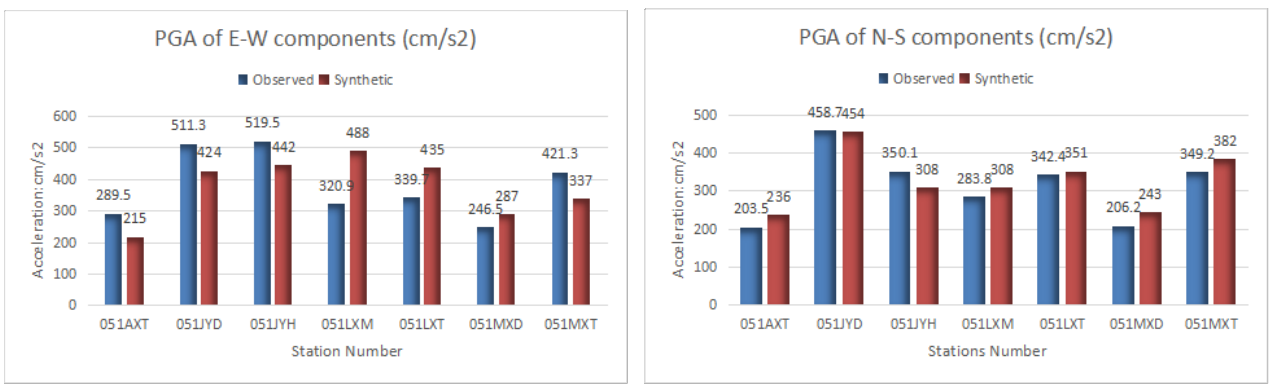


Fig.4 Simulation and comparison of Station 051MXD, Upper figures (black) means observed data while below figures (red) means synthetic data.

These strong stations' results showed that simulated time-histories are similar with observed time histories. PGA between synthetic values and observed values was also similar. Synthetic results could reflect real time-histories' characteristic basically. There is something we should pay more attention here. When we simulated ground motion, we should select a good section of time histories. We trimmed the beginning and the end of the time histories in this study.

There was also another phenomenon, the synthetic PGA of station 051AXT, 051JYD, 051JYH, 051MXT were smaller than observed PGA in E-W component, while the rest of stations' result were opposite in E-W component. In the N-S components, the synthetic PGA of stations is higher than observed PGA except station 051JYD and 051JYH, which are shown in Figure5. This phenomenon maybe had relationship with complicated terrain. The terrains of Station 051JYD and 051JYH are gentle slope terrain, while the terrains of other stations are complicated mountains. Complicated terrain conditions may amplify or reduce the PGA value.



(a) (b)

Figure.5 PGA Comparisons between observed data and synthetic data, Figure5a is E-W components while Figure5b is N-S components.

Site conditions have also very large effect on PGA. For example, rock condition or soil condition could amplify or shrink peak acceleration. In the fifth generation of *seismic ground motion parameters zonation map of china*, the values of PGA is depended on different site condition. In this study, the site conditions of these stations are all the soil.

4.2 Result of abnormal intensity region

In this Part, we chose 3 strong earthquake stations' data for simulation, which are 051HYJ, 051SMC and 051SMX. Because of paper length limit, only stations051SMC's simulated results were listed in this section. The simulated results were shown in Fig.6 and Fig.7.

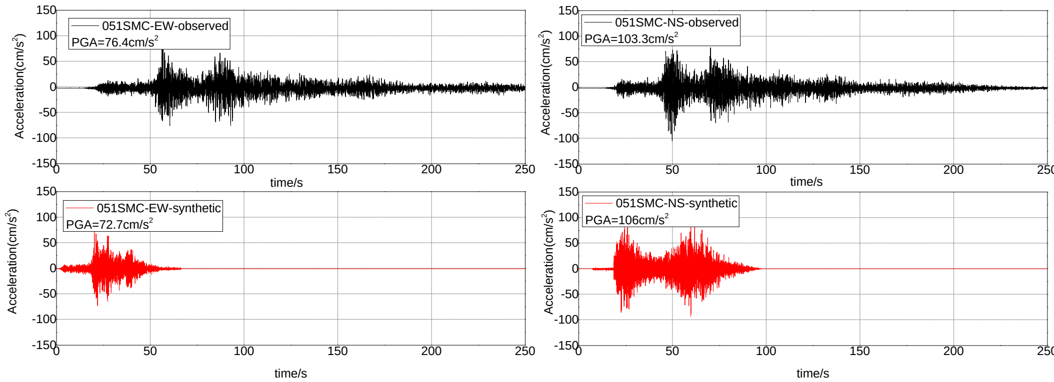


Fig.6 Simulation and comparison of Station-051SMC, Upper figures (black) means observed data while below figures (red) means synthetic data.

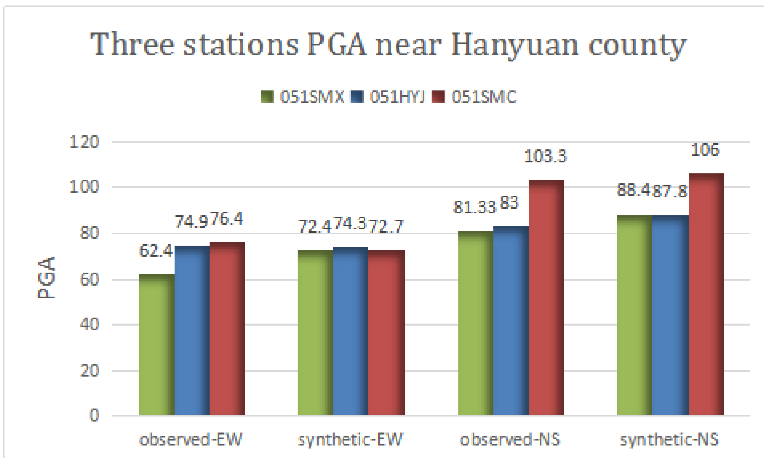


Figure.7 PGA Comparisons between observed data and synthetic data

The results showed that simulated PGA is similar with observed PGA. The high values section of time history between synthetic values and observed values was also similar. Synthetic results could reflect real PGA characteristic basically. The earthquake (Ms5.0) was appropriate as green function when aftershock (Ms5.8) can't play the role of green function well. Another phenomenon is that N-S component of PGA is generally higher than E-W component. This may be caused by fault directivity.

The site conditions of the three stations are all soil. The terrains in this area are canyon and mountains. There are also many small faults in this area which have different strike as shown in Fig.1. Combining the complicated terrains in this zone, earthquake wave may cause reflection and refraction many times by the underground complex structures. These factors result in the amplification of ground motion. This reason may explain the abnormal intensity in Hanyuan-county also.

5 Principles of choosing green function

The similarity degree of focal mechanism is an important criteria of choosing small earthquakes [1,2,6]. This aftershock should have a good signal-to-noise ratio [6]. If a large number of smaller events appropriately distributed over the fault are used for the synthesis, the appropriately is improvable. However, another problem is indicated by Chouet *et al* (1978) that the similarity assumptions of earthquakes show some departures for smaller earthquakes. Thus, for our synthesis we should use small earthquakes with appropriate size which can be related to the main-shock in accordance with the similarity condition [1]. For the higher frequency simulation, we'd better choosing a small event having the fault length $Le = \tau \cdot \upsilon_\tau$ (υ_τ: rupture velocity, and τ: rise time of main-shock).

In this study, we also summarized several principles. First of all, the distance between main-shock source and aftershock source should be as close as possible. Secondly, both main-shock and aftershock occurred in the same fault plane. Thirdly, the stations should be closed with source location in the near field. Fourthly, the acceleration record of aftershock should have obvious S-wave components. When the earthquake record is not good or lacking, we could try choosing small earthquake from another similar region, such as similar site conditions, similar hypo-center distance, high sign-to-noise ratio etc.

6 Conclusion and discussion

The simulated results showed that, the time-histories records of high amplitude acceleration section are similar between observed values and synthetic values. Synthetic PGA is fitting better with observed PGA at the whole stations while synthetic PGA is a bit smaller than observed PGA in complicated terrain regions. This may be caused by terrains and site conditions in this area, and site conditions have very large effect on PGA.

Empirical green function method is feasible for simulating strong ground motion. The synthetic results could reflect well the near-field seismic characteristic of Wenchuan earthquake. But because the source rupture progress of Wenchuan earthquake is too complicated, simulation results still have room for improvement. Three important factor, source, propagation medium in-homogeneity and site conditions, should be seriously considered when we use empirical green function to simulate earthquake. Some uncertainty factors, such as rupture style, rupture starting point, choosing small earthquake *et al*, should also be paid attention.

The abnormal intensity regions appeared generally causing by propagation medium and field environment, such as site conditions, terrains, faults strike and quantity etc. It is very hard to find out where is the normal intensity in a simulation progress. It has very large uncertainty. Maybe we could get the empirical abnormal intensity region by statistical analysis to correct simulated result.

Acknowledgements

This research work is supported by China National Special Fund for Earthquake Scientific Research in Public Interest(North-South Seismic Belt, North Belt and South Belt; Seismic Safety Evaluation Classification-Key Technology index determination-National Standard Revision Research): (201308011; 201008001; 201408002), National Natural Science Foundation: (51278470; 51678537; 50808162). National Science Technology Support Plan Projects: Ground Motion Basin Effect Research (2012BAK15B01-05) and Special Fund of the Institute of Geophysics, China Earthquake Administration: (DQJB11C15) and Key Laboratory of Seismic Observation and Geophysical Imaging Project. Data for this study are provided by China Strong Motion Network Centre at Institute of Engineering Mechanics, China Earthquake Administration.

References

[1] Irikura, K.(1983): Semi-empirical estimation of strong ground motions during large earthquakes[J]. *Bulletin of the Disaster Prevention Research Institute*, **33**(2), 63-104

[2] Irikura, K.(1986): Prediction of strong acceleration motion using empirical Green's function[C]. *Proceedings of 7th Japan Earthquake Engineering Symposium*, 151-156.

[3] Irikura K, Miyake H.(2011): Recipe for predicting strong ground motion from crustal earthquake scenarios[J]. *Pure and Applied Geophysics*, **168**(1-2), 85-104.

[4] Miyake, H., Iwata, T., & Irikura, K. (1999): Strong ground motion simulation and source modeling of the Kagoshima-ken Hokuseibu earthquakes of March 26 (M_{JMA}6.5) and May 13 (M_{JMA}6.3), 1997, using empirical Green's function method. *Zisin*, **51**, 431-442. (in Japanese with English abstract).

[5] Miyake, H., Iwata, T., & Irikura, K. (2001): Estimation of rupture propagation direction and strong motion generation area from azimuth and distance dependence of source amplitude spectra. *Geophysical research letters*, **28**(14), 2727-2730.

[6] Miyake, H., Iwata, T., & Irikura, K. (2003): Source characterization for broadband ground-motion simulation: Kinematic heterogeneous source model and strong motion generation area. *Bulletin of the Seismological Society of America*, **93**(6), 2531-2545.

[7] Ye, L., Ma, Q., Miao, Z. et al.(2013): Numerical and comparative study of earthquake intensity indices in seismic analysis[J]. *The Structural Design of Tall and Special Buildings*, **22**(4), 362-381.

[8] Chen, D., Duan, R.(2013): Amplification effects of site conditions on ground peak accelerations. *Earthquake Engineering and Engineering Vibration*, **33**(1), 24-30.

[9] Wang, X.Y., Nie, G.Z., Zhang, L. (2010): Relationship between landslides induced by the Wenchuan earthquake and Arias Intensity. *Journal of Basic Science and Engineer*, **18**(4), 645-656.

[10] Hartzell, S.H.(1978): Earthquake aftershocks as Green's functions[J]. *Geophysical Research Letters*, **5**(1): 1-4.

[11] Somerville P, Irikura K, Graves R, et al.(1999): Characterizing crustal earthquake slip models for the prediction of strong ground motion[J]. *Seismological Research Letters*, **70**(1), 59-80.

[12] Xie Junju.(2010): Characteristics of Near-fault Strong Motion from Ms8.0 WenChuan earthquake[D]. *Beijing: Institute of geophysics, china earthquake administration*. (in Chinese)

[13] GB18306-2015(2015). Seismic ground motion parameters zonation map of China[S]. *Beijing: China Standard Press.*

[14] Hu Yuxian(2006). Earthquake engineering (second edition)[M]. *Beijing: Seismological Press*.

[15] Aki K.(1968). Scaling law of seismic spectrum[J]. *Journal of Geophysical Research*, **72**(4): 1217-1231.

[16] Beresnev I A, Atkinson G M.(1999) Generic finite-fault model for ground-motion prediction in eastern North America[J]. *Bulletin of the Seismological Society of America*, **89**(3): 608-625.

[17] Brune J. N.(1970). Tectonic stress and the spectra of seismic shear waves from earthquakes[J]. *Journal of geophysical research*, **75**(26): 4997-5009.

[18] Boore D M(1983). Stochastic simulation of high-frequency ground motions based on seismological models of the radiated spectra[J]. *Bulletin of the Seismological Society of America*, **73**(6A): 1865-1894.

[19] Boore D M, Atkinson G M.(1987) Stochastic prediction of ground motion and spectral response parameters at hard-rock sites in eastern North America[J]. *Bulletin of the Seismological Society of America*, **77**(2): 440-467.

[20] Boore D M. (2003). Simulation of ground motion using the stochastic method[J]. *Pure and applied geophysics*, **160**(3-4): 635-676.

[21] Haskell N A.(1964) Total energy and energy spectral density of elastic wave radiation from propagating faults[J]. *Bulletin of the Seismological Society of America*, **54**(6A): 1811-1841.

[22] Haskell N A.(1969) Elastic displacements in the near-field of a propagating fault[J]. *Bulletin of the Seismological Society of America*, **59**(2): 865-908.

[23] Hanks T C, Kanamori H.(1979). A moment magnitude scale[J]. *Journal of Geophysical Research*, **84**(B5): 2348-2350.

[24] Kanamori H.(1977). The energy release in great earthquakes[J]. *Journal of Geophysical Research*, **82**(20): 2981-2987.

[25] Tao Xiaxin, Wang Guoxin.(2003). Rupture directivity and hanging wall effect in near field strong ground motion simulation. Acta Seismologica Sinica, **25**(2): 191-198 (in Chinese).

[26] Shen Z K, Sun J, Zhang P, et al.(2009). Slip maxima at fault junctions and rupturing of barriers during the 2008 Wenchuan earthquake[J]. *Nature Geoscience*, **2**(10): 718-724.

[27] Yao X D, Zhang W B, Yu X W.(2015). Simulation of near-field strong ground motion caused by the 2008 Ms8.0 Wenchuan earthquake. *Chinese J. Geophys.*, **58**(3):886-903 (in Chinese).