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# Research on Shakemap of Peak Ground Acceleration with Bias Correction for Ludian *M*s6.5 earthquake on 3 Aug 2014

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## *Abstract*

On 3 August 2014 a great earthquake of Ms6.5 struck Yunan province. The epicenter (27.1°N, 103.3°E) of the earthquake was located in Ludian county Zhaotong City, with a focal depth of 12km according to China Earthquake Administration. This catastrophic event caused extensive casualties and heavy engineering damage in a wide area. The earthquake caused 615 deaths, 114 missing and 3,000 people injured and a large number of houses collapsed and damaged. Considering the geological context, focal mechanism solutions, aftershock distribution, strong-motion peak accelerations and attenuation characteristics of the ground motion in western China, shakemap of PGA (Peak Ground Acceleration) for the Ludian was investigated.

In order to reduce the uncertainty of the small value peak acceleration, this paper selected 22 strong-motion peak acceleration with PGA greater than 10gal, using Bias correction method to Correct ShakeMaps of the peak acceleration before. Considering the effect of local site effects, the PGAs of observation stations on surface were converted to the reference surface bedrock. Then abnormal data, outside three times the standard deviation of peak acceleration attenuation relationship, was excluded. Deviation factor (c0 = -2.89; c1 = 1.58) between observed value and estimated value of PGA attenuation relationship can be derived from the log-linear fitting peak acceleration. The estimates of PGA in area without stations were adjusted with the above deviation factor (c0, c1). Finally, considering the effects of local site, the estimates of PGA on bedrock were corrected to the value of the surface, interpolating with real observations to acquire the contour maps of peak ground acceleration. Relationship between PGA and intensity was consistent with the Chinese seismic intensity scale (GB17742-2008)

The results shown that decay rate of the peak ground acceleration versus distance for this earthquake was faster than the peak acceleration attenuation relationship of Western China (derived from the 258 earthquake). Results of logarithmic bias correction were more consistent with attenuation of this earthquake. An area with PGA greater than 40gal after correcting is nearly 8,000 square kilometers, which is reduced by about 40%.

*Keywords: Distribution of Peak Ground Acceleration， LuDian earthquake， Bias correction;*

## 1. Introduction

A great earthquake of Ms6.5 struck Yunan province on 3 August 2014. The epicenter (27.1°N, 103.3°E) of the earthquake was located in Ludian county Zhaotong City, with a focal depth of 12km according to China Earthquake Administration. This catastrophic event caused extensive casualties and heavy engineering damage in a wide area. The earthquake caused 615 deaths, 114 missing and 3,000 people injured and a large number of houses collapsed and damaged.

Epicenter of Ludian earthquake is located near the Zhaotong - Ludian fault. Zhaotong - Ludian fault composed of two NE-trending thrust faults [1-2]. In the past, several earthquakes took place in this tectonic belt and its adjacent areas, especially in the past decade. For example: Ludian Ms5.0 and Ms5.1 earthquake in 2003, Ludian Ms5.6 earthquake in 2004, two Ms5.1 Yunnan Yinjing earthquakes in 2006. Yunnan Yiliang Ms5.6, 5.7 earthquakes in 2012 and Yunnan Yongshan Ms5.3 earthquake in 2014. Therefore, the seismic activity of this area is very active.

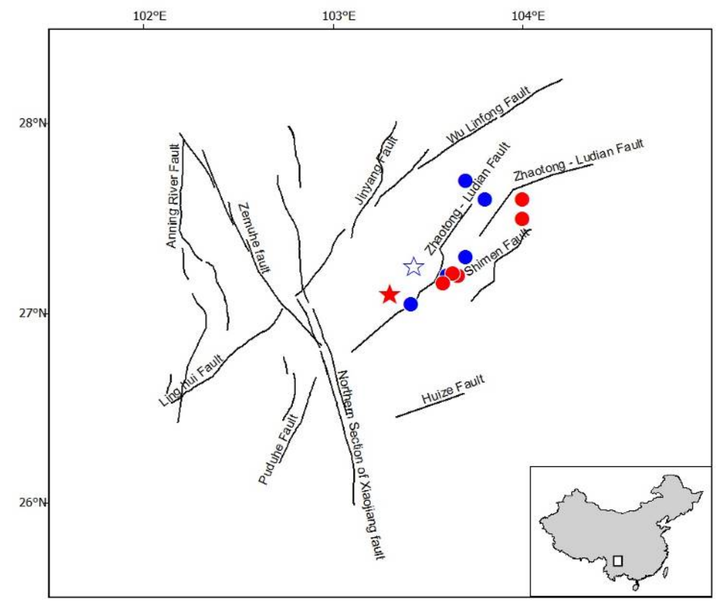



Fig.1 The tectonic background of the Ludian earthquake

The red star indicate the earthquake location results from China earthquake networks center; the blue star indicate the earthquake location results from USGS; The blue circle indicate earthquake before 2000; The red circle indicate earthquake after 2000; the black line indicate the fault.

Within a short time after the earthquake occurred, the first version shakemap of PGA (Peak Ground Acceleration) for the Ludian *M*s6.5 earthquake on 3 Aug 2014 was acquired, in which the mothed of rapid generation ShakeMaps considering site effects was used [3-4]. Information utilized to acquire the first version ShakeMaps includes tectonic background of the Ludian earthquake, ground motion attenuation relationship in the western China and Local site effect. Then the shakemap for the Ludian Ms6.5 earthquake have been gradually amended many times based on the collected data (seismic data from National Seismic Network, focal mechanism solutions, rupture process, strong motion acceleration records and location of aftershocks, etc.) [5-7]. we hope corrected ShakeMaps can provide scientific basis to emergency rescue, earthquake relief and earthquake damage assessments.

## 2. Data

Ludian Ms6.5 earthquake happened near Zhaotong - Ludian fault. Strike of this fault is generally northeast, and geochronology is early Pleistocene thrust fault [8]. seismic moment tensor solution of China Earthquake Administration and US Geological Survey for this earthquake displayed as strike-slip earthquake, and one of the two nodal planes for this earthquake was strike 74 °, dip 84 °, rake 177 °; the other was 165 °, dip 87 °, rake 6 °. [9-10]. Seismic moment tensor solution of strike-slip earthquake is not consistent with thrusting fault of Zhaotong - Ludian fault, and strike of Zhaotong - Ludian fault is also different from the two nodal planes of seismic moment tensor solution. From The tectonic background of the Ludian earthquake, this area is the intersection of two directions of faults. Both north-east and north-west faults Co-exist in this area, which is the mechanism of frequent earthquakes occurrence. According to the second nodal planes of seismic moment tensor solution and of aftershocks and distribution of aftershocks[9], the direction of the seismogenic structure of this earthquake is determined to NW.

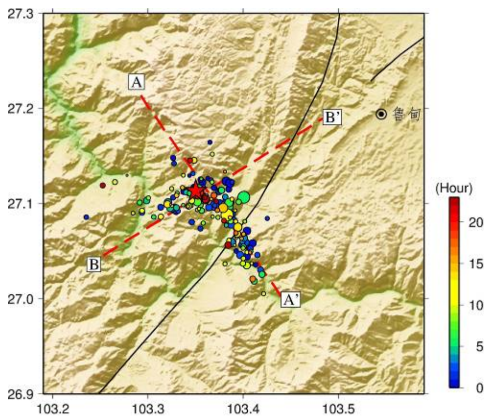



Fig.2 Distribution of the Ludian Ms6.5 earthquake sequences(Provided by Dr. Fang Lihua)

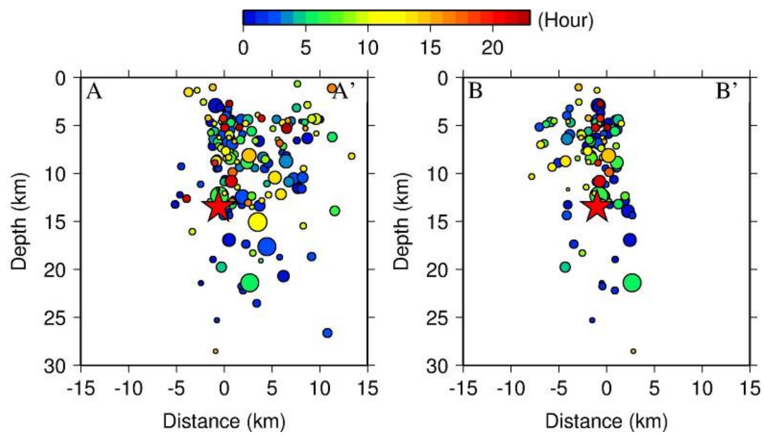



Fig.3 the focal depth distribution of the earthquake sequences after relocation in the vertical direction along profile AA′ and BB′

The blue star and circles indicate the main shock and aftershock sequences after relocation, respectively. The color bar indicate the elapsed time from the main shock to the earthquake sequences

Coordinates scope of the study area was from 101.5° to 105°E and from 25.5° to 28.5°N, respectively. Local site amplification effect was considered in different versions ShakeMaps for Ludian Ms6.5 earthquake. Vs30(the average shear-velocity down to 30 m) can be acquired with the correlation between slope and Vs30, came from United States Geological Survey (USGS), considering the characteristics of division between active tectonic regions and stable continental regions in China[3-4,11-13]. PGA on bedrock can be computed, using position of the epicenter, tectonic background information of the Ludian earthquake, seismic moment tensor solutions and relocation of aftershocks. Attenuation relationship for peak ground acceleration of Wang Suyun(2000) was selected to compute to ground motion parameter on bedrock in Ludian earthquake(referred to herein Wang2000)[14], and the long axis of this ellipse attenuation relationship is determined as 165°. Finally, according to site effect coefficients [15], which are relate to amplitude and frequency of ground motion parameter, and characterized by Vs30, PGA on bedrock can be convert to the surface of soil. ShakeMaps of PGA for Ludian earthquake can be acquired.

Acceleration records of this Ludian Ms6.5 earthquake mainly come from National Earthquake Observation Center, and 54 pairs of acceleration records can be collected. In addition, 11 pairs of acceleration records of Institute of Geophysics, China Earthquake Administration composed Qiaojia earthquake observatory array, also be collected. PGAs of seismic-station are shown in the attached table, and seismic-station coverage displayed in Fig3. PGA of ShakeMaps for Ludian earthquake is maximum of PGA in two horizontal directions.

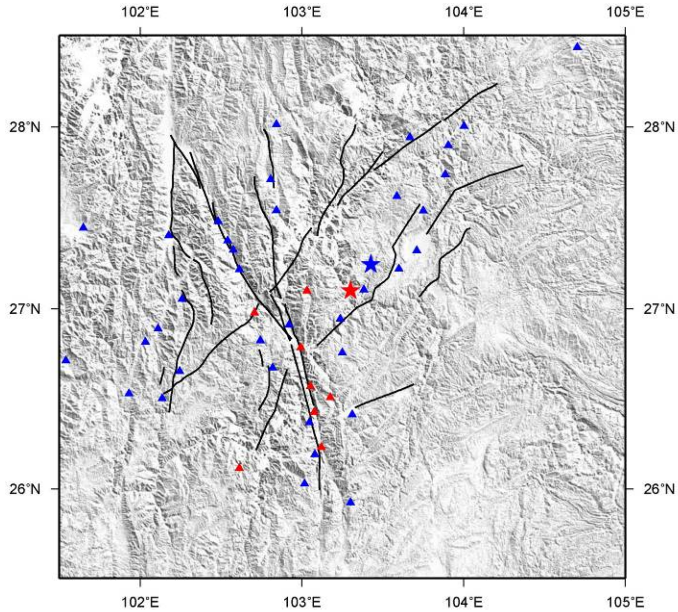



Fig.4 Distribution of seismic-station

The red triangles indicate seismic-station of Institute of Geophysics, China Earthquake Administration composed Qiaojia earthquake observatory array. The blue triangles indicate seismic-station of National Earthquake Observation Center; others are the same as Fig.1.

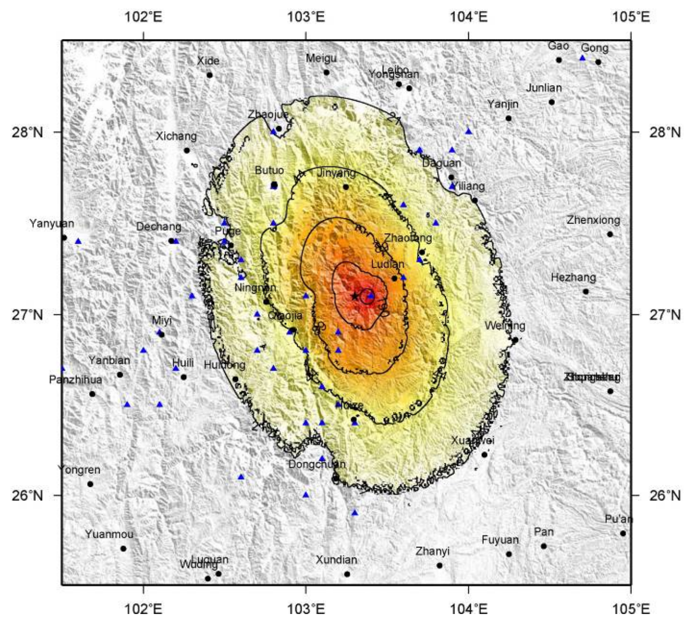
## 3. Method

For uncorrected peak ground acceleration ShakeMaps, the peak ground acceleration values of uniform grid points on bedrock within work area were calculated with the epicenter of this earthquake and the long axis of the ellipse orientation attenuation model using rapid generated ShakeMaps method [4]. Further, considering the local site effect of ground motion, peak ground acceleration values on bedrock were convert to the surface soil, and peak ground acceleration values on surface can be obtained. Estimates of peak ground acceleration for uniform distributed grids less than 15km from the actual station will be removed, and peak ground acceleration observed value of the actual stations were uses as the interpolation points. Finally, spatial distribution of peak ground acceleration on the surface can be obtained using the inverse distance weighting (IDW) spatial interpolation method, as shown in fig.5a. The contour intervals are consistent with relationship between peak acceleration and intensity in GB17742-2008[16].

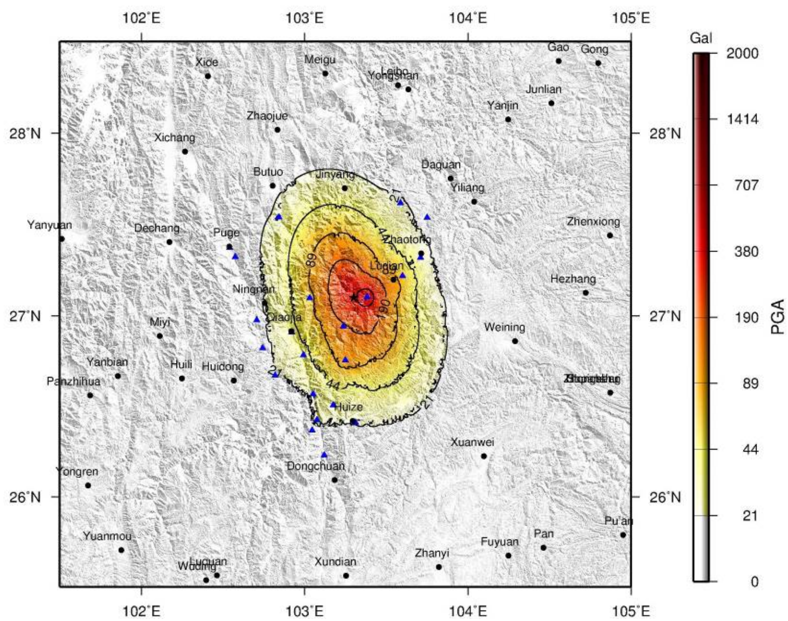
Records came from earthquakes of different focal mechanisms were all used in peak ground acceleration attenuation relationships of Wang Suyun 2000, and types of seismogenic fault for earthquakes cannot be distinguished in this attenuation relationships. Secondly, inter-event residual in attenuation relationship for the same magnitude earthquakes exists. Usually, there is system deviation between the estimated and observed value of seismic station for specific seismic events often between the calculated [6].

22 peak ground acceleration greater than 10cm/s2 were selected in this paper in order to reduce the uncertainty small peak ground acceleration values may bring. The corrected ShakeMaps of peak ground acceleration can be acquired using ShakeMaps correction method with strong motion records[5-7]. In this mothed, observed value of seismic station on soil surface is converted to bedrock considering the local site effect. Then abnormal observed data greater or less than three times the standard deviation of the peak acceleration attenuation relationship may be eliminated. Deviation factor between the estimated and observed value of seismic station can be obtained using Log-linear least squares fitting (respectively $c0 = -2.89$; $c1 = 1.58$), as shown in fig.6. Estimated value of peak ground acceleration in areas absence of seismic station can be corrected with the deviation factor (c0, c1) mentioned above. Finally, consider the effect of local site, corrected estimates of peak ground acceleration on bedrock is converted to surface soil, and with peak ground acceleration

observations interpolation and contour were done. Distribution maps of peak ground acceleration can be obtained, as shown in fig.5b. Attenuation relationship of this study is elliptical model, and short axis distance of the ellipse, not epicentral distance, was used in fig.7.




(a)




(b)

Fig.5 ShakeMaps of peak ground acceleration for The Ludian Ms6.5 earthquake on 3 Aug 2014

(a. Without correction; b. corrected with observations of peak ground acceleration)

The blue triangles indicate seismic-station. The black points indicate county.

## 4. Discuss

Shakemap of PGA for LuDian earthquake considering local site effects, focal mechanism, aftershock sequences after relocation and observed value of peak ground acceleration is shown in fig.5a, in which the observed values of peak ground acceleration were only used as interpolation. It can be seen from fig.5a that distribution direction of the ShakeMaps of PGA for LuDian earthquake was NNW. The maximum of peak ground acceleration was greater than 380cm/s$^2$ (seismic intensity Ⅸ), and the epicenter was located outside this region(greater than 380cm/s$^2$), mainly because observed value of PGA on seismic station of Longtaosan was 949.1cm/s$^2$. PGA of Ludian County is located between 89 and 190 cm/s$^2$ (seismic intensity Ⅶ). Seismic intensity of Jinyan and Qiaojia county is perhaps Ⅵ, because they are located near the isoseismic line of 44 cm/s$^2$ . The area of greater than 40cm/s$^2$ is around 13,000 square kilometers. Although Zhaotong City is located near isoseismic line of 44 cm/s$^2$, but the observed value of peak ground acceleration on Zhaotong seismic station is only 14.9cm / s$^2$, Which resulting in a significant acceleration anomaly. Northwest isoseismic line of 44cm/s$^2$ is obvious concave, because of lower observed values on seismic stations (respectively 17 and 2.4 cm/s$^2$).

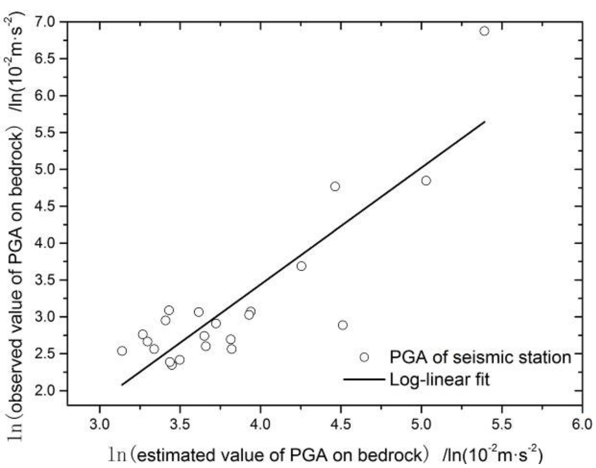



Fig.6 Relationship by Logarithmic fitting observed values and estimated values on bedrock for The Ludian Ms6.5 earthquake on 3 Aug 2014

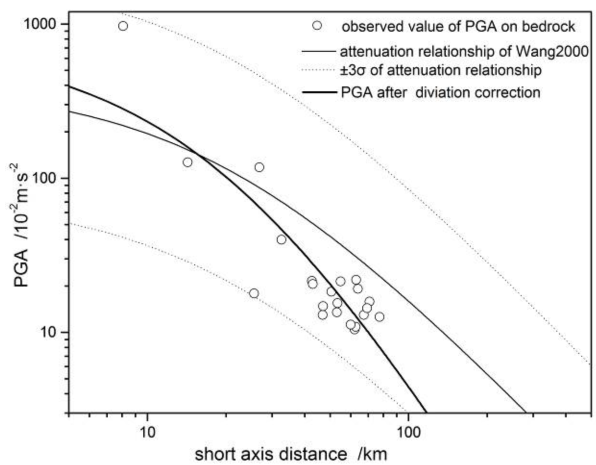



Fig.7 Result of bias correction for The Ludian Ms6.5 earthquake on 3 Aug 2014

Corrected ShakeMap of peak ground acceleration was shown in fig.5b. And bias correction results with observed PGA value greater than 10 cm/s$^2$ were shown in fig.6-7. It can be seen from fig.6-7 that observed peak ground acceleration greater than 10cm /s$^2$ in Ludian earthquake were all located within ± 3δ of peak ground acceleration attenuation relationship of Wang Suyun(2000), but decay with distance more quickly than attenuation relationship of Wang2000. And bias correction in this paper was in line with observed peak ground acceleration. As shown in fig.5b, the area with PGA greater than 44cm/s$^2$ after bias correction was nearly 8,000 square kilometers, and equivalent to 60% of area with PGA greater than 44cm/s$^2$ before bias correction. Span of area with PGA greater than 44cm/s$^2$ is about 80km along SEE, and 120km along NNW. Highest value of peak ground acceleration contour in ShakeMap of PGA after bias correction was still 380cm/s$^2$, and Longtoushan township was located within areas greater than 380cm/s$^2$.

Ludian Ms6.5 earthquake on 3 August 2014 caused heavy casualties and economic losses. Object of this study aims to providing distribution of peak ground acceleration as soon as possible, according to the limited information collected after the earthquake. We hope that ShakeMap of PGA can provide basic information for earthquake damage assessment, seismic geological hazard assessment, emergency rescue, earthquake relief and scientific research. The damage caused by the earthquake is associated with the extent of shaking caused by the earthquake, but the actual earthquake damage evaluation results mainly from the consequences of the earthquake influences. Seismic intensity (vibration intensity) in this article is the direct associated with ground motion parameters, and there are some differences between vibration intensity and actual investigation intensity. Nevertheless, distribution of vibration intensity in this paper also was compared with actual investigation intensity map. the results showed that the both spatial distribution were roughly equivalent, but area above intensity Ⅵ in this paper is slightly smaller than that of the actual survey intensity, mainly because of more emphasis on the small value of the observations outside 40cm/s$^2$ contour in this paper. in short period after Ludian Ms6.5 earthquake without the results of focal mechanism solutions, rupture process, the aftershock positioning distribution and enough observed seismic station, the long axis of ellipse attenuation model can be determined primarily based on tectonic background and distribution of active faults. However, if the earthquake take place in areas of complex geological structure, especially in the newborn seismogenic fault region, based on tectonic background determination the long axis of ellipse attenuation model is not very accurate. Based on seismic information of this earthquake, gradual correction ShakeMap step by step is very necessary. In addition, data from seismic stations and strong motion station outside study area is also helpful to determine orientation of the long axis of ellipse attenuation model.

## 4. Acknowledgements

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## 5. Copyrights



## 5. References

References must be cited in the text in square brackets [1, 2], numbered according to the order in which they appear in the text, and listed at the end of the manuscript in a section called References, in the following format:

[1] Zhang P Z (2008): The tectonic deformation, strain distribution and deep dynamic processes in the eastern margin of the Qinghai-Tibetan plateau. *Science in China Series D: Earth Sciences* (in Chinese), 38(9), 1041-1056.

[2] Wen X Z, Du F, Yi G X, et al (2013): Earthquake potential of the Zhaotong and Lianfeng fault zones of the eastern Sichuan-Yunnan border region. *Chinese J. Geophys.* (In Chinese), 56(10):3361-3372.

[3] Wald D J, Worden B C, Quitoriano V,Pandow K L （2006）： ShakeMap Manual: Technical manual, user's guide, and software guide: U.S. Geological Survey, 156p.

[4] Chen K, Yu Y X, Gao M T（2010）: Research on ShakeMap System in terms of the Site effect.*Earthquake Research in China*, 26(1):92-102(in Chinese).

[5] Chen K, Yu Y X, Gao M T, et al (2012): Study on bias correction of ShakeMaps based on limited acceleration records. *Acta Seismologica Sinica*, 34(5):633-645(in Chinese).

[6] Chen K, Yu Y X, Gao M T (2013a): Research on Correction Method of ShakeMap based on Seismic Data. *Journal of Basic Science and Engineering*, 21(4): 679-691 (in Chinese).

[7] Chen K, Yu Y X, Gao M T, et al(2013b): Shakemap of Peak Ground Acceleration with Bias Correction for the Lushan, Sichuan Earthquake on April 20, 2013[J]. *Seismology and Geology*, 35(3):627-633 (in Chinese).

[8] Xu X W，Yu G H(2014)：Picture of seismogenic structure for Ludian Ms6.5 earthquake (27.1° N, 103.3° E),Yunnan province. [EB/OL]. [2014-8-3]. http://www.eq-igl.ac.cn/admin/upload/files/云南6_5级地震发震构造图0805.jpg.

[9] Institute of geophysics, China earthquake administration (2014): August 3, 2014 Ludian 6.5 earthquake, Yunnan province. [EB/OL]. [2014-8-3]. http://www.cea-igp.ac.cn/tpxw/270724.shtml.

[10] USGS (2014): M6.1-11km WNW of Wenping,China[EB].[2014-2-12].http://earthquake.usgs.gov/earthquakes/eventpage/usb000rzmg#scientific.

[11] Allen T I, Wald D J (2007):Topographic Slope as a Proxy for Seismic Site-Conditions (Vs30) and Amplification around the Globe: *U.S.Geological Survey Open-File Report 2007-1357*, 69p.

[12] Allen T I and Wald D J(2009): On the use of high-resolution topographic data as a proxy for seismic site conditions (VS30), *Bull. Seism. Soc. Am.*, 99(2A):935-943.

[13] Wald D J, Allen T I (2007):Topographic Slope as a proxy for Seismic Site Conditions and Amplification. *Bull.Seism.soc.Amer*, 97(5): 1379-1395.

[14] Wang S Y, Yu Y X, Gao A J, et al (2000): Development of Attenuation Relations for Ground Motion in China. *Earthquake Research in China*, 16(2):99-106(in Chinese)

[15] Borcherdt R D (1994): Estimates of site-dependent response spectra for design (methodology and justification). *Earthquake Spectra*, 10: 617-654.

[16] China Earthquake Administration(2001): *The Chinese seismic intensity scale (GB17742-2008)* [S].Beijing：China Standard Press.