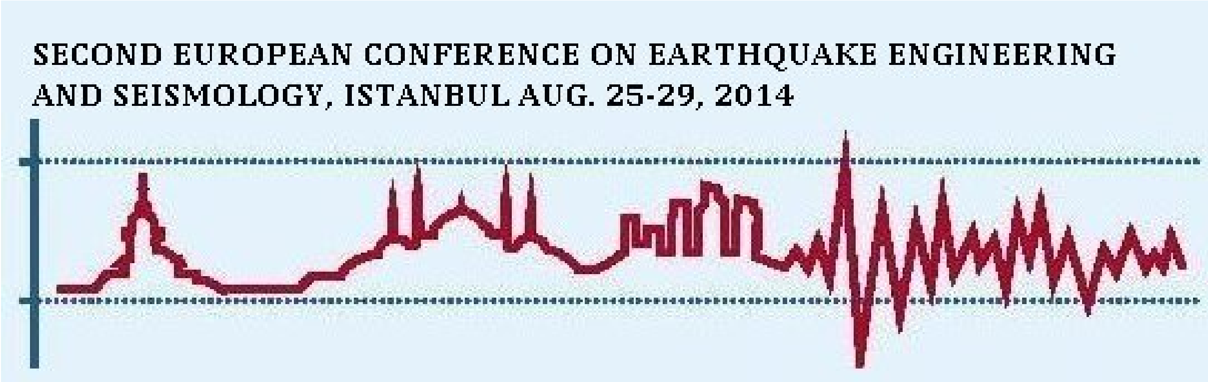

ON STRONG GROUND MOTION AND MACRO-SEISMIC INTENSITY OF LUSHAN MS7.0 EARTHQUAKE

Yushi WANG[1], Xiaojun LI[2]

ABSTRACT

We analyzed the strong-motion records and macro-seismic intensity of Lushan Ms7.0 (Mw6.6 by USGS) earthquake shocking the middle of Sichuan province, China at 08:02 Beijing Time (00:02 UTC) on April 20, 2013. The distribution of PGA, instrumental seismic intensity, as well as spectral accelerations derived from strong-motion records did not revealed that significant directionality effect as the macro-seismic intensity map of this earthquake. More illustrations on the philosophy of macro-seismic intensity evaluation in China indicated that the macro-seismic intensity below VII was not a reliable index of strong-motion severity in China.

INTRODUCTION

The Lushan earthquake on 20 April 2013 occurred on the southern segment of the Longmenshan fault, and the central-northern segment of the same fault induced the Wenchuan earthquake on 12 May 2008. The magnitude of Lushan earthquake was non-unique with an acceptable error, of which Ms7.0, and Mw6.6 were considered to be the most reliable measures of the energy released (Liu RF et al., 2013). The most accurate and reliable rupture initiation point (hypocenter) was located at 30.289±0.005°N, 102.946±0.007°E, and depth of 11.8±2.3 km by means of the Time-Reversal Imaging Technique (Xu LS et al., 2013).

The Lushan earthquake was not accepted as an aftershock of the Wenchuan earthquake (Liu J et al., 2013; Du F et al., 2013), even though the Lushan earthquake and the Wenchuan earthquake occurred on the same fault in less than 5 years, and there was probably a close relationship between them. There was an interval of about 45 km between the aftershock areas of two events, and there was no intersections of the two source ruptures (Zhang Y et al., 2013; Wang WM et al., 2013).

Strong ground motion induced by the Lushan Earthquake could be felt in Middle Sichuan, whereas the most serious devastation occurred in only several townships in Lushan county. The collapse of masonry structures and wooden houses, landslides, and other ramifications caused the deaths of 196 people and the injuries of more than ten thousands. The direct economic losses were estimated to be about RMB 176 hundred million (Li CS et al., 2013).

OBSERVED STRONG GROUND MOTION

The mainshock and aftershocks of Lushan Earthquake were well recorded by NSMONS (National Strong Motion Observation Network System) of China. The violently affected area had been

[1] Associate professor, Institute of Geophysics, China Earthquake Administration, 5th Minzudaxuenan Rd., Beijing, China, wysh.igp@gmail.com
[2] Professor, Institute of Geophysics, China Earthquake Administration, 5th Minzudaxuenan Rd., Beijing, China

chosen as one of the regions prone to disastrous earthquake before Lushan earthquake, and strong motion stations were densely distributed and continuously operated there since March 2008 (Li XJ et al., 2008). During the mainshock of Lushan earthquake, 123 sets of three-component accelerograms were recorded in Sichuan, Yunnan, and Gansu province, as shown in Fig. 1. As 32 set of these accelerograms did not record long enough, we only used 91 sets of them to get reliable PGAs and spectral accelerations.

MACRO-SEISMIC INTENSITY AND INSTRUMENTAL INTENSITY

One hour after the event, Institute of Geophysics, China Earthquake Administration announced the first version of strong ground motion prediction map (ShakeMap), and updated it soon after (http://www.cea-igp.ac.cn/upload/Image/mrtp/tpxw/2013n/2013n4r/2669133725.jpg). Five days after the event, the on-site emergency team of China Earthquake Administration published the macro-seismic intensity map based on damage severity of 360 survey points and 231 sample points in 21 counties(http://www.cea.gov.cn/publish/dizhenj/468/553/100342/100343/20130426121539151743491/index.html).

The macro-seismic intensity map was more extensive in the south direction than in the north direction of the epicentre, as shown in Fig. 2. As an earthquake characterized with bilateral rupture concentrated in an relatively small area of 25km×25km (Xu LS et al., 2013; Zhang Y et al., 2013), this significant asymmetry properties of macro-seismic intensity could no be convincingly explained by the heterogeneous properties of the focal mechanism.

Days after the event, we calculated the instrumental intensity of recorded accelerograms. The intensity metric used here was modified spectral intensity, which was similar to Housner's spectrum intensity (Housner GW, 1952), with the caveat that its numerical value was modified by evaluating the predominant period of spectral acceleration and the site characteristics of each strong-motion station(Wang YS et al., 2013). The sparse points of instrumental intensity shown in Fig. 2 did not indicate any obvious asymmetries along the north-south direction.

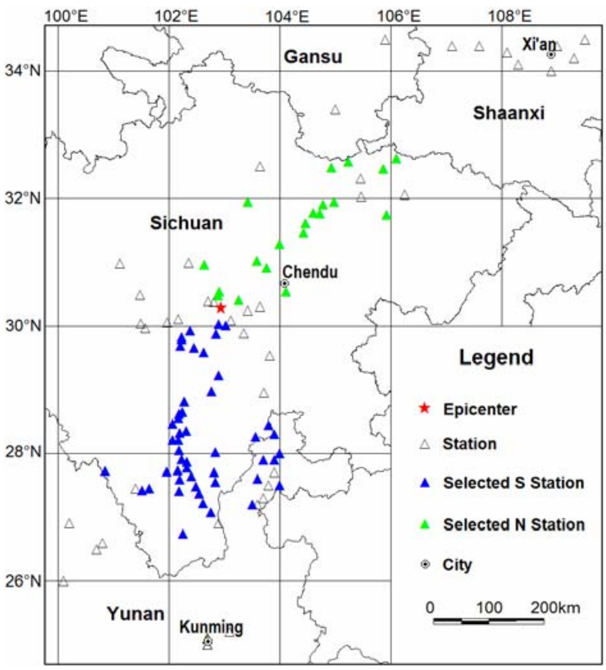

Fig. 1 Station locations that recorded accelerograms

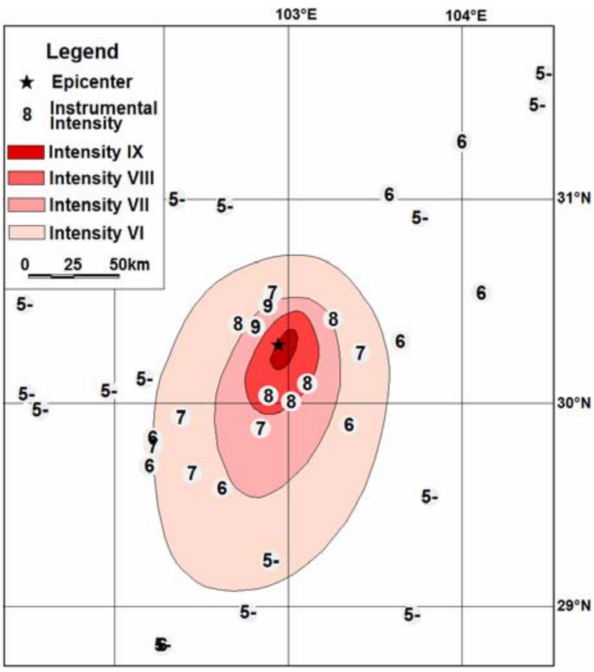

Fig. 2 Macro-Seismic intensity of Lushan earthquake

STRONG GROUND MOTION ATTENUATION

We selected 50 sets of free-field accelerograms in south of the epicentre, and 20 sets in north, to investigate the strong ground motion attenuation characteristics with distances, and their corresponding station locations were shown in Fig. 1 as blue triangles for southern stations and green triangles for northern stations. We used the Joyner-Boore distances (Boore DM and Joyner WB, 1982; Boore DM and Atkinson WB, 2008) to investigate the attenuation of strong ground motion, which were calculated from the focal geometry of this event given by Zhang Y et al. (2013). In this study, the horizontal peak ground motion was defined as PGAs and spectral accelerations at periods T=0.3s, 1.0s, and 3.0s of an individual East-West component or North-South component.

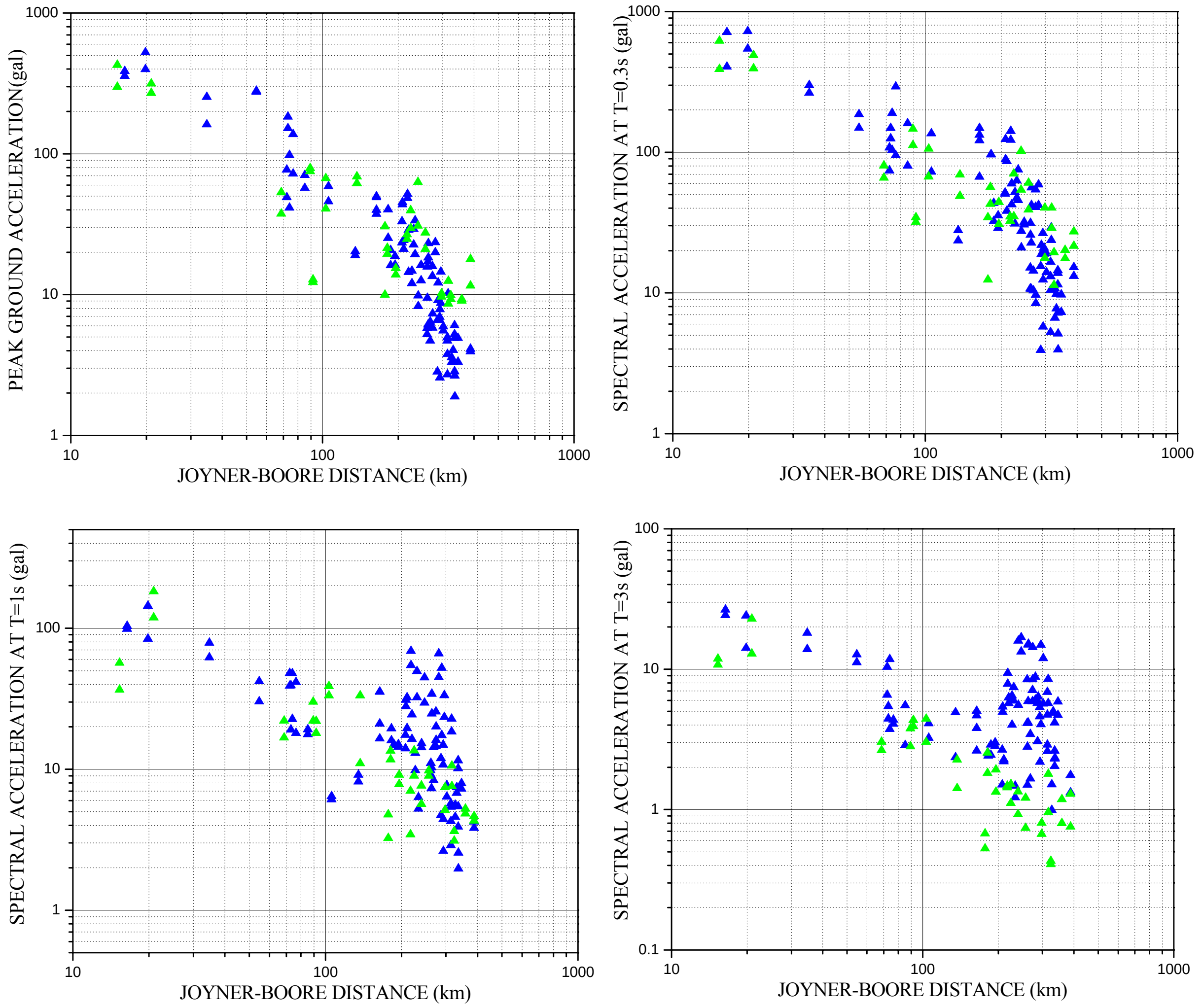

Fig. 3 The attenuation characteristics of PGAs and spectral accelerations at periods 0.3s, 1.0s, and 3.0s.

As shown in Fig. 3, there was no obvious discrepancy between the strong ground motion in south and north of the epicentre inside the macro-seismic intensity ≥VI areas whose Joyner-Boore distances were less than 150km. Within these areas, the PGAs, as well as spectral accelerations at periods T=0.3s, 1.0s, or 3.0s, were comparable in both sides of the epicentre along the north-south direction.

However, the spectral accelerations at periods T=1.0s and 3.0s displayed different characteristics in far-field with Joyner-Boore distances >150km, as the ones in south of the epicentre were much larger than the ones in north of the epicentre. This inconsistent trend was caused by surface geology effect of ground motion, for almost all the southern stations with Joyner-Boore distances >150km were located on intermontane basins with considerable quaternary overburden layers, such as the narrow and long Xichang basin covered with soft soil. Meanwhile, the northern stations with the same distances were almost located on rock sites or shallow and hard soil sites.

PHILOSOPHY OF MACRO-SEISMIC INTENSITY EVALUATION IN CHINA

The standard definition of macro-seismic intensity in China was “the severity of ground motion caused by earthquakes and its influences” (Sun JJ et al, 2008), but the macro-seismic intensity investigators preferred to accept the latter half of this definition as macro-seismic intensity was “the severity of earthquake influences” rather than “the severity of ground motion”. The reason for this ambiguity was that the ground motion severity was hard to evaluate directly by investigators without accelerograms, whereas it was much easier to evaluate the damages of buildings.

The direct consequences of evaluating macro-seismic intensity by damages was to evaluate building vulnerability as EMS98 did (Grünthal G,1998), and to distinguish the actual reason of building damages. In some traffic-inconvenience areas of China, small proportions but larger amounts of rural buildings were of poor seismic resistance properties, as shown in Fig.4. Relatively weak ground motion would aggravate their old damages caused by uneven settlement of foundations or landslides before. Meanwhile, the north half of the affected areas of Lushan earthquake were in the rebuilt areas of Wenchuan earthquake, all buildings with poor seismic resistance properties there had been rebuilt with high quality, as shown in Fig.5, and little damages could be found in the rebuilt buildings in intensity VI areas of this event.

If the considerable differences in seismic resistance properties of rural buildings were not attentively considered, incompatibilities of macro-seismic intensity would appear, such as in the macro-seismic intensity map of Lushan earthquake. One extreme example happened in Yiliang Ms5.7and Ms5.6 earthquakes on 7 Sep. 2012. The PGAs of accelerograms at Station 53GNSS in two earthquakes were no larger than 15gal, as shown in Fig.6, but the intensity around this station was mistakenly evaluated to be intensity VI based on the building damages caused by uneven settlement of foundations before the earthquake. In order to let the macro-seismic intensity be a metric of ground motion severity, differences in building vulnerability must be carefully considered as EMS98 did. Before that, the distribution of intensity <VII was not a reliable index of ground motion severity in China, for the disparity of building vulnerability could mislead the macro-seismic intensity evaluation.

Fig.4 A rural building with poor seismic resistance property in intensity VI area in south of Lushan earthquake epicentre. The spider web and dusts on it indicated that the cracks in the brick load-bearing wall were not directly damaged by the Lushan earthquake. The probably reason for these cracks were uneven settlement of foundations before the event, which were very common in mountain areas of Western China.

Fig.5 A rural building with high seismic resistance property in intensity IX area in the rebuilt area of Wenchuan earthquake, whose filler walls cracked but load-bearing walls and beams were undamaged.

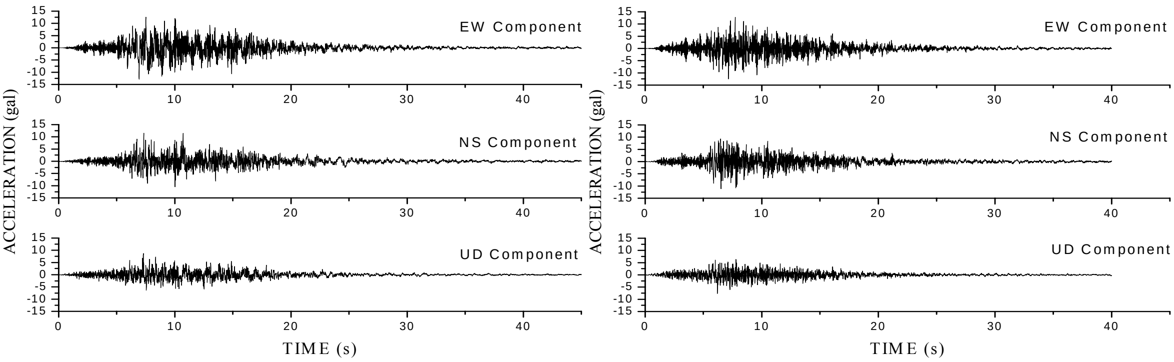

Fig.6 The accelerograms of Station 53GNSS in Yiliang Ms5.7 (Left) and Ms5.6 (Right) earthquakes. This station was located in the intensity VI area. The amplitudes of shaking were so small, and it was hard to believe that the building damages around this station were directly caused by ground motion.

CONCLUSIONS

We used 123 sets of three-component accelerograms to analyze the strong ground motion caused by Lushan Ms7.0 (Mw6.6) earthquake. The PGAs, instrumental seismic intensity, as well as spectral accelerations at periods 0.3s, 1s, and 3s indicated that the strong ground motion did not show obvious asymmetry properties as the macro-seismic intensity map did. The reason for these incompatibilities between strong ground motion and macro-seismic intensity was the absence of building vulnerability in macro-seismic intensity evaluation.

In order to make the macro-seismic intensity reflect the severity of ground motion more precisely, differences in building vulnerability must be carefully considered during macro-seismic intensity evaluation as EMS98 did. Before that, the distribution of intensity <VII was not a reliable index of ground motion severity in China, for the disparity of building vulnerability could mislead the intensity evaluation to a great extent as in Lushan earthquake.

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