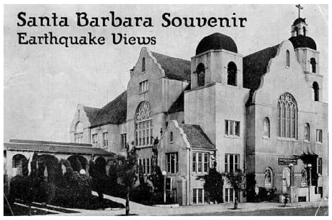

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RECENT EXPERIENCE AND PRACTICE
FOR STRONG MOTION OBSERVATION IN CHINA

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ABSTRACT

The history of strong motion observation in China is briefly reviewed firstly and then the new generation of strong motion network, National Strong Motion Observation Network System (NSMONS) of China built in the 10th National Five-year Plan, is introduced. The performance of this network is evaluated by recent earthquakes in Chinese Mainland, including the Great Wenchuan Earthquake. After Wenchuan Earthquake, it's realized that NSMONS functionality should be not just for strong motion data collection, but should be extended to quick strong motion estimation and damage field evaluation. To follow the new requirement of the earthquake mitigation plan, some new practice are described, including rapid urban ShakeMap, earthquake early warning project. Finally, some current problems are presented and analyzed, and then some suggestions are proposed.

1 INTRODUCTION

In recent years, earthquakes happened frequently in China and have caused enormous losses of life and property to human society. The devastating Wenchuan earthquake, which occurred on May 12, 2008, caused massive human casualties and property losses, and brought about immeasurable sufferings to the Chinese people. The National Strong Motion Observation Network System (NSMONS) of China which was built in the 10th National Five-year Plan, has been fully put into service since March 2008 and the Wenchuan earthquake happened to give a good chance to evaluate it and this also is a milestone in Chinese strong motion history. NSMONS is useful for research and implementation in engineering and strong-motion seismology. In this paper, Chinese strong motion history is reviewed and some experience and practice for strong motion is introduced.

2 STRONG MOTION OBSERVATIONS IN CHINA

The strong ground motion observation in China was initiated by the effort of Pro.Liu Huixian, the pioneer of earthquake engineering in China, in 1956 and the strong motion research group founded in Institute of Engineering Mechanics, China Earthquake Administration, in the winter of 1960. After the operation of the Xingfengjiang Reservoir in Guangdong Province in 1959, a series of induced-earthquake occurred and after the M_s6.1 main shock occurred in March of 1960, the strong motion stations were installed at the dam of the reservoir for measuring its aftershocks, which marked the beginning of the strong motion observation era in China, and then the first analog strong motion recording was obtained in 1961. In 1965, the first roadmap for the strong motion network was complied and the first generation team for the strong motion observation was trained, and the 6-line strong motion instrument was produced in Institute of Engineering Mechanics, China Earthquake Administration, as shown Fig. 1, and this marked the beginning of initial strong motion instrument production in China. At the end of 1971, a stipulation on China strong motion observation was proposed and the strong motion observation array for the Nanjing Yangtze River Bridge was installed in 1973, which obtained the valuable recordings from Liyang M_s6.0 Earthquake in August 9, 1979 (Xie, L. and S., Yu, 1982).
Xingtai Earthquake was a sequence of major earthquakes that took place between March 8 and March 29, 1966 in the area North China and the mobile strong ground motion observation was practiced in China firstly and has been proven that it is an effective way to capture more strong ground motion data. At that time, analog strong-motion network in China was very sparse and mobile strong motion observation may loss the chance to obtain the main shock, but the feature of its immediacy and portability could perform well

during the aftershock events. Usually the aftershocks attenuated after the main shock, both in the events and intensity. Thus if the mobile instruments could be installed quickly, more data could be captured. It was the seismic active period from 1966 to 1976 in Chinese mainland and mobile method is proven as an efficient way in that time. Table 1 shows mobile strong motion observation for a series of earthquakes during 1966-1976 and some of the analog strong motion recordings are still popular used today.

Table 1. Mobile Strong Motion Observation in China during 1966 to 1976

No	Date	Name	Magnitude
1	October 2, 1966	Changchun Earthquake	5.2
2	March 27, 1967	Hejian Earthquake	6.7
3	July 18, 1969	Bohai Region	7.4
5	July 26, 1969	Yangjiang Earthquake	6.4
6	January 5, 1970	Tonghai	7.8
7	March 23 and 24, 1971	Wuqia Earthquake	6.0 and 6.1
8	February 4,1975	Haicheng Earthquake	7.3
9	May29, 1976	Longling Earthquake	7.3 and 7.4
10	July 28, 1967	Tangshan Earthquake	7.8
11	Aug 16, 1976	Songpan and Pingwu Earthquake	7.2

With the prosperous strong motion observation research in China, Chinese scientists were actively promoting international exchanges and cooperation. Bruce A. Bolt, the seismologist from Berkeley Seismological Laboratory, gave the suggestion and performed evaluation of Chinese strong motion instruments and strong motion recordings in 1974 and the Chinese earthquake engineering delegation visited the USA in the same year. From 1976, Institute of Engineering Mechanics, China Earthquake Administration conducted the processing of the strong motion recordings and then those published gradually, which the user could required most of the digitized data for free.

Since then a serials of strong motion arrays were starting to run, which cooperated with USA and other countries, such as Tangshan Experimental Array, Babaoshan storage Array, and so on. Fig. 2 shows the West Yunnan earthquake field Array in Yunnan Province staring in 1983, which still have some stations deploying SMA accelerograph and will be soon replaced by the digital instruments. The first telemetric array of rapid seismic intensity was established around Beijing in 1990's, which consists of 80 dial-up strong motion stations and 72 real-time satellite transmission strong motion stations. Since 1980's, the free-field observation has been in the majority, while some ones are on some typical structures. Up to 2002, there are totally 488 strong motion stations in the networks, but most of the instruments belong to analog (Gao, G., *et al*., 2001; Li, S.Y., *et al*., 2003 and Wang, F. and P., Hu, 2006).

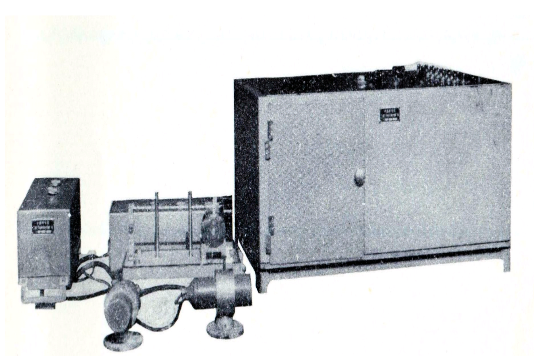

Fig. 1. 6-line strong motion instrument in the early stage of China in 1960's

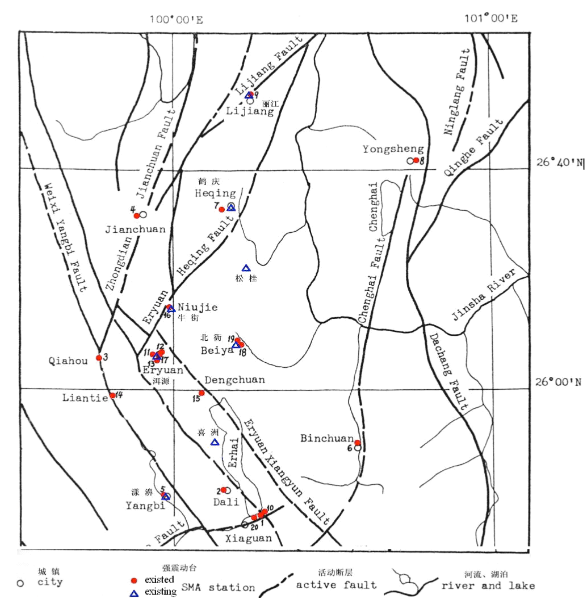

Fig. 2. West Yunnan Earthquake Field Array (From 1983)

During the national 10th Five-year Plan from 2000 to 2005, funded by the central government, China Digital Strong Motion Observation Network (NSMONS) was established for the large scale strong motion observation network in the mainland. The network system consists of 1,154 permanent free-field stations, 12 special observation arrays, 200 mobile instruments and a strong motion observation network management system. The average inter-distance between strong motion stations is about 50 km around the special area. At present, each station equips with the 3-channels accelerometer, and most of which work in dial-up mode and send data through modems. In addition, some ones send real-time data through a TCP/IP protocol with the better observation circumstances. The management system includes a national center, three regional centers, five centers for rapid reporting of seismic intensity and local branch centers in every provinces, municipalities and autonomous regions. Its main service is the data record collection, processing and dissemination, network technical support, network management and maintenance, etc. China Earthquake Administration and Provincial Earthquake Administration are responsible for information service on earthquake activities.

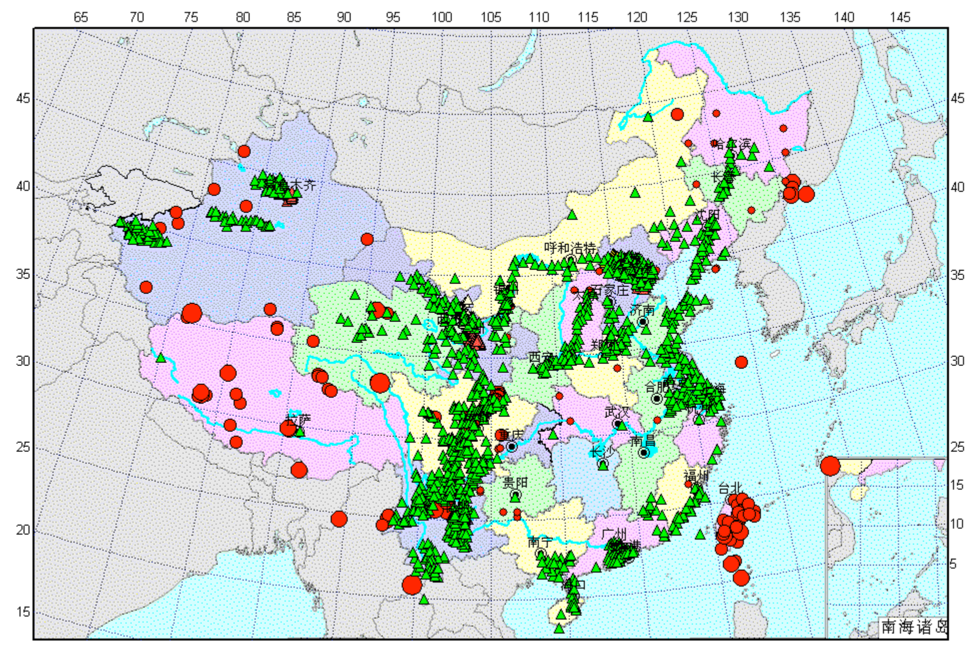

Fig. 3. National Strong Motion Observation Network System of China (Epicenters M≥4.0 2007-2011)

3 RECENT EARTHQUAKE EXPERIENCES

It has been four years since NSMONS ran formally. In order to evaluate the performance of NSMONS, Fig.3 shows the seismicity from 2007 to 2011(M≥4.0) in China and we also buffered the earthquake influence area of the each event by the ground motion prediction equation. We set the ground motion 5cm/s^2 as the lower limit of those influence areas, as it is the triggered threshold of the accelerograph of NSMONS. Those buffered area can be used for evaluating the possible triggered numbers of strong motion station for each earthquake, as shown in Fig.4.

Figure 4 also shows the station distribution of NSMONS corresponding with the high seismicity in National seismic zoning map of China (2001) (Gao,M.T., 2003), as shown in Fig. 5. The site selection of NSMONS station has been generally a compromise between the network geometry, which depends on the National seismic zoning map, and the criteria that the selected site must be suitable for building and maintenance. From Fig.4, it can be seen that the strong motion stations within Sichuan Province could be having the greatest effect on the network, since there are too many Wenchuan aftershocks.

From Jan 2007 to Dec 2009, only 346 stations had reported the triggered strong motion events from 11 provincial earthquake administrations, measured 185 earthquakes in Chinese Mainland and around region, not including Wenchuan mainshock and its aftershocks. Total 2498 sets of strong motion recordings were obtained and Fig.6 shows the numbers vs. PGA for EW, NS and UD component. For some destructive earthquakes, such as Yushu Earthquake, Panzhihua Earthquake, Yaoan Earthquake and Yingjiang Earthquake, those epicenters did not fall within the network or locate at the boundary of network, so most of the PGA is much small and the sum for PGA greater then 50gal is only 117 form 2007-2009 (China National Strong Motion Center, 2011). In Tibet, NSMONS could not cover the remote region and there were no response for those earthquakes. At the same time it should be noticed that in the east China, most of strong motion stations are at operational state, but don't react due to the scarcity of destructive earthquakes. Compared to the active seismicity in west China, destructive earthquake occurred only occasionally in the east part of China, and the dense strong-motion network in this area was highlighted by the occurrence of small earthquakes.

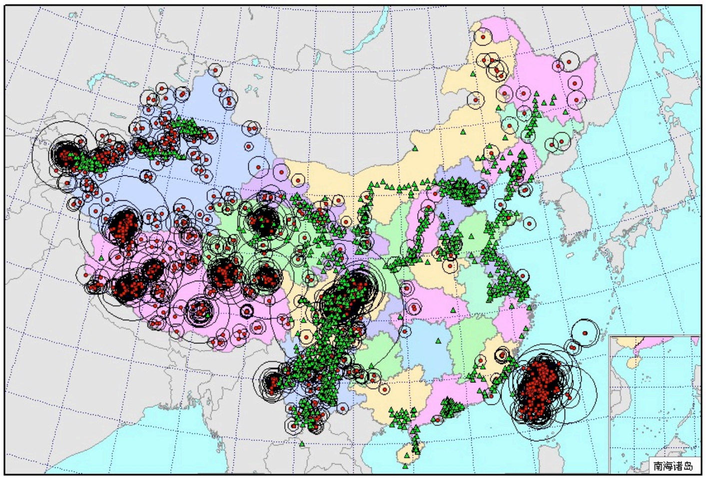

Fig. 4. Epicenters with buffered area (M≥4.0 2007-2011)

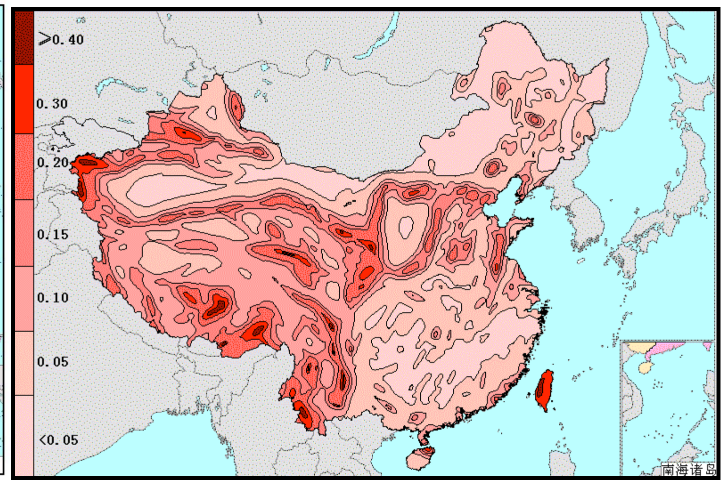

Fig. 5. National seismic zoning map of China (2001)

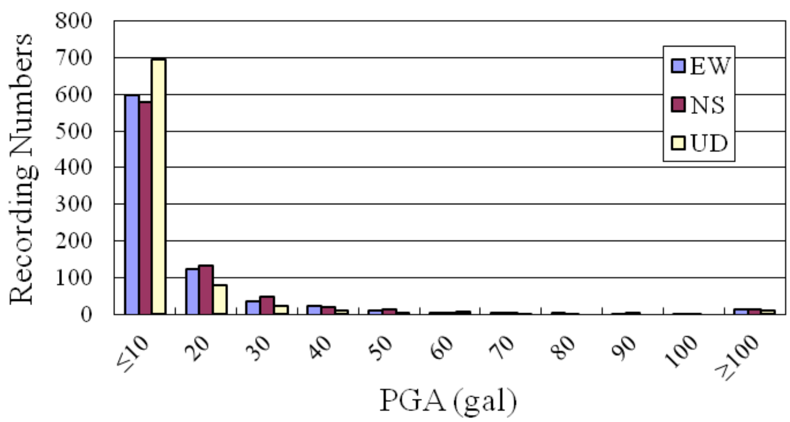

Fig. 6. Distribution number of strong motion records (Jan 2007 to Dec 2009)

<u>3.1 Wenchuan Earthquake</u>

NSMONS began trial operation in early 2007 and formal operation in March 2008. Luckily it was just the two months later that the network experienced the Great Wenchuan Earthquake on May 12, 2008 and obtained a large number of recordings from 460 stations in 17 provinces, municipalities and autonomous regions and three arrays in Sichuan and Yunnan provinces. More detailed analyses of these recordings from the mainshock were conducted by Li, X., *et al*. [2008a] and Li, X., *et al*. [2008b]. Although in Wenchuan mainshock, 460 strong motion stations had been triggered in 17 provinces and 1253 recordings were collected, the station density of NSMONS is lower and still could not cover all the seismic effected area (China National Strong Motion Center, 2009a). In order to follow the trend of aftershocks, total 59 sets of instruments had been temporarily deployed to capture Wenchuan aftershocks and 92 sites had been observed, of which the locations are shown in Fig. 7 (China National Strong Motion Center, 2009b).
Until October 10, 2008, the mobile network had captured 3250 3-channel acceleration recordings and the distribution of the aftershock epicenters which had been observed by the mobile network is shown in Fig. 8 and Table 2 (China National Strong Motion Center, 2009b).

3.2 Other destructive earthquakes

Here are some typical earthquakes which could give the performance of NSMONS. The epicenters of Yushu Earthquake, Panzhihua Earthquake, Yaoan Earthquake and Yingjiang Earthquakare shown in zoomed Fig.9.

(1) The 2010 Yushu Earthquake struck on April 14, 2010, with a magnitude of M_s7.1. The earthquake occurred on the Yushu fault, which is one part of the Yushu-Garzê-Xianshuihe fault zone, one of the most active fault zones in eastern Tibet. Finally 2,698 people have been confirmed dead, 270 missing, and 12,135 injured and the Chinese intensity is VIII around Jiegu Town. The nearest station from NSMONS was about 350km, only 5 stations triggered which the max peak reached to only 2gal and the others were just a little higher than the background noise level. After the main shock, 4 mobile stations were set up to capture aftershocks around the Yushu Country.

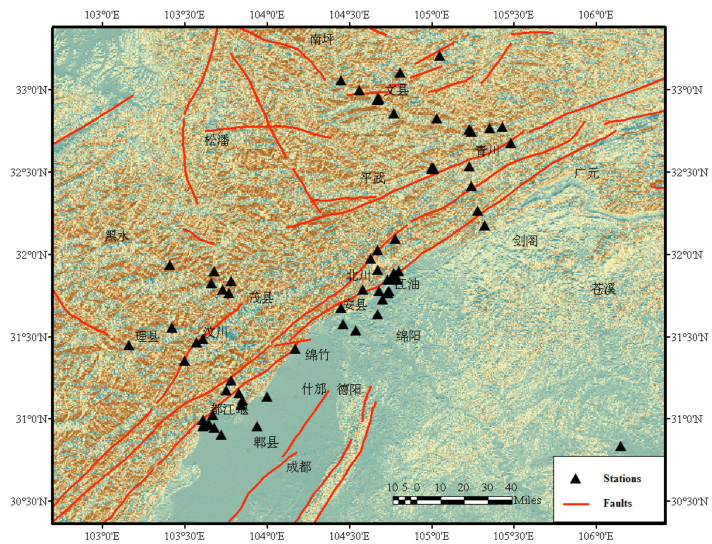

Fig. 7. Mobile station network for Wenchuan Aftershocks

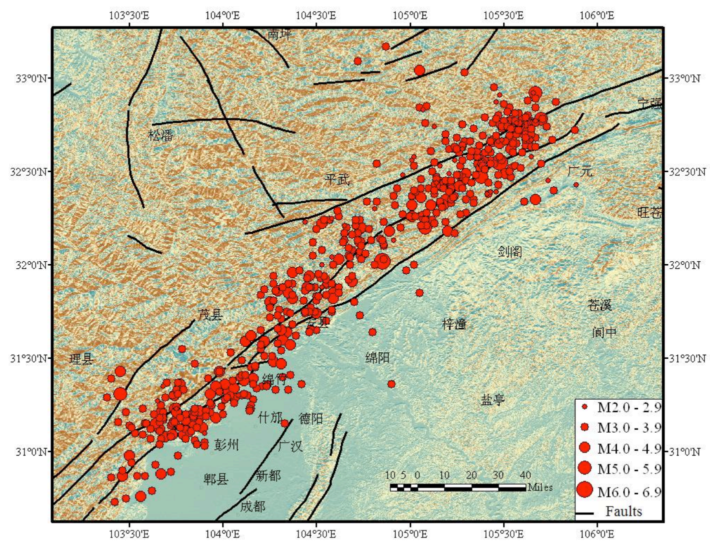

Fig. 8. Wenchuan aftershocks recorded by mobile station (May12,2008- October 10, 2008)

(2) The 2008 Panzhihua Earthquake struck on August 30, 2008 with a magnitude M_s6.1, just two months after Great Wenchuan Earthquake. 36 people have been confirmed dead, and 467 injured. The seismic intensity map shows a maximum seismic intensity is VIII and the area affected by intensity VIII covered a north-south oriented eclipse of 628 km^2, 39km long and 19km wide, including 28km^2 in Yunnan province. More than 50 strong motion stations triggered. The nearest station is within 10km away from the epicenter and the max horizontal peak acceleration is 491gal and 535gal in NS and EW component, respectively, and other high-quality near-field strong motion recordings, of which PGAs vs. epicenter distances is shown in Fig. 10

Table 2. Summary of the acceleration recordings for Wenchuan mobile observation (Before October 10, 2008)

No.	Institutions Name	Recording number
1	Institute of engineering mechanics, CEA	1599
2	Gansu Provincial Earthquake Administration	1505
3	Yunnan Provincial Earthquake Administration	100
4	Sichuan Provincial Earthquake Administration	46
Sum		3250

(3) The Yaoan Earthquake occurred on July 9, 2009 with a magnitude M_s6.0 and only 1 people have been confirmed dead, and 328 injured. The seismic intensity map shows a maximum intensity is VIII .The macro epicenter was located on the Yaoan Country and

the VIII area was about 230km^2. The nearest station from NSMONS was about 30km and most of about 100km away from the epicenter. Due to the epicenter is about 200km away from the Kunming Urban Rapid Intensity System, and most of the stations around Kunming triggered, which the epicenter distance with the PGA could be seen in Fig 11.

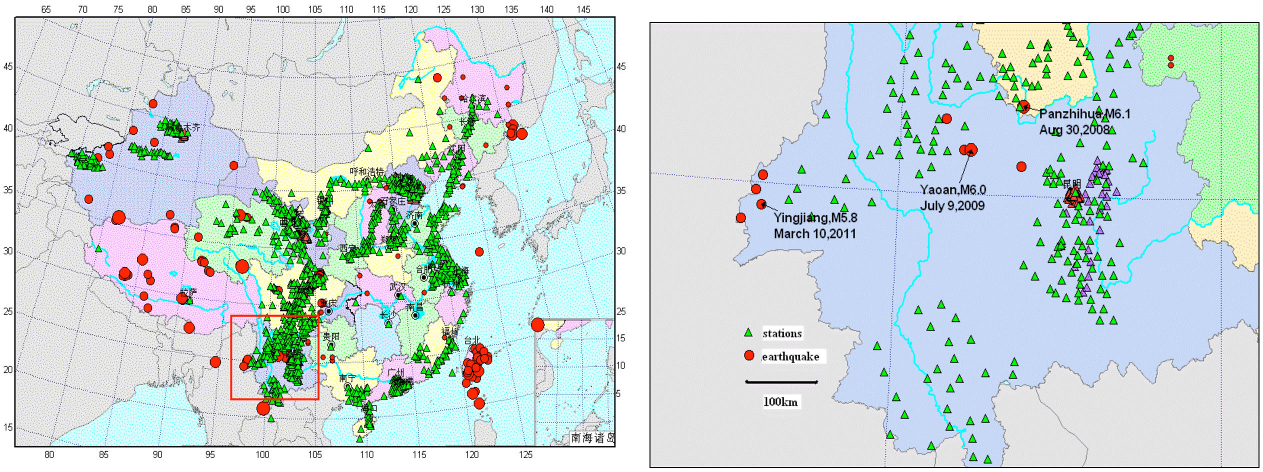

Fig. 9. Three destructive earthquakes in Yunnan Province and around region

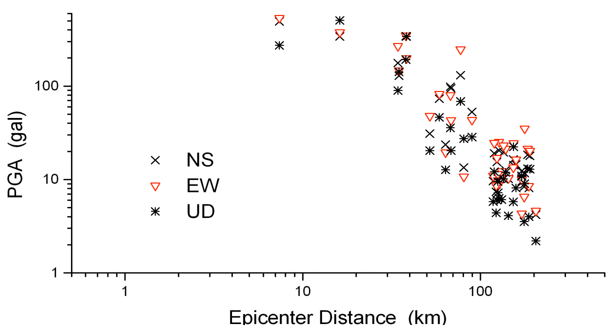

Fig. 10. PGA vs. epicenter distance in Panzhihua Earthquake

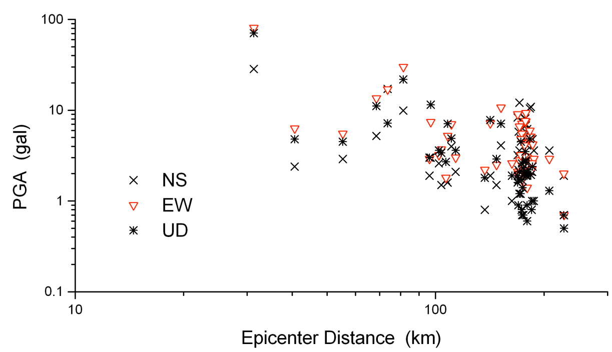

Fig. 11. PGA vs. epicenter distance in Yaoan Earthquake

(4) The 2011 Yingjiang Earthquake was an M_s5.8 magnitude earthquake that occurred on 10 March 2011, with its epicenter in Yingjiang County, near Burmese border. The epicenter was 2 kilometers from the center of the county and caused total 26 people died and 313 were injured with 133 in serious condition and the center of the county was evaluated as VIII. The nearest strong motion station is about 100km away from the epicenter, so the ShakeMap was applied for the ground motion estimation and loss investigation, as shown in Fig.12. After main shock, 5 mobile strong motion stations were set up for the aftershock observations. Since 2008, there were a series of major earthquakes in this area and those 5 mobile stations would change to permanent stations under the local government's request.

4 RECENT PRACTICES

(1) Construction of a legal framework related with strong motion observation
China Earthquake Administration plays a great important role in forming the legislation of earthquake prevention and disaster reduction and has enacted a number of laws and regulations in the recent years, the strong motion observed objects have been extended to nuclear power station, arrays on local site effect, topography effect and so on. Since last 10 years, it has promulgated more than 10 code and regulations. In the Law of the People's Republic of China on Protecting Against and Mitigating Earthquake Disasters, it is suggested that the reservoir, oilfield and nuclear plant should set up the strong motion observation system according to in Article 19. The national codes or earthquake industry standards giving the new requirement or suggestion for the strong motion

observation or data application are listed:

- GB 18306－2001, Seismic ground motion parameter zonation map of China
- GB 17741－2005, Evaluation of seismic safety for engineering sites
- GB 21075－2007, Reservoir-induced earthquake hazard assessment
- GB/T 17742－2008, The Chinese seismic intensity scale
- GB/T 19428－2003, Code for earthquake disaster evaluation and its information management system

Chinese Strong Motion Observation Committee was initiated in 2010 under the Society of Chinese Seismology and the committee will keep on functioning as the coordinator on strong motion observation activities in China. Meanwhile, during Wenchuan earthquake, the instruments operating experience demonstrates the need for a systematic servicing procedure, with attentions paid to such potential power interruption, power surges, data transmission etc. Right now the related regulations and codes are undertaking with the finical support of the government.

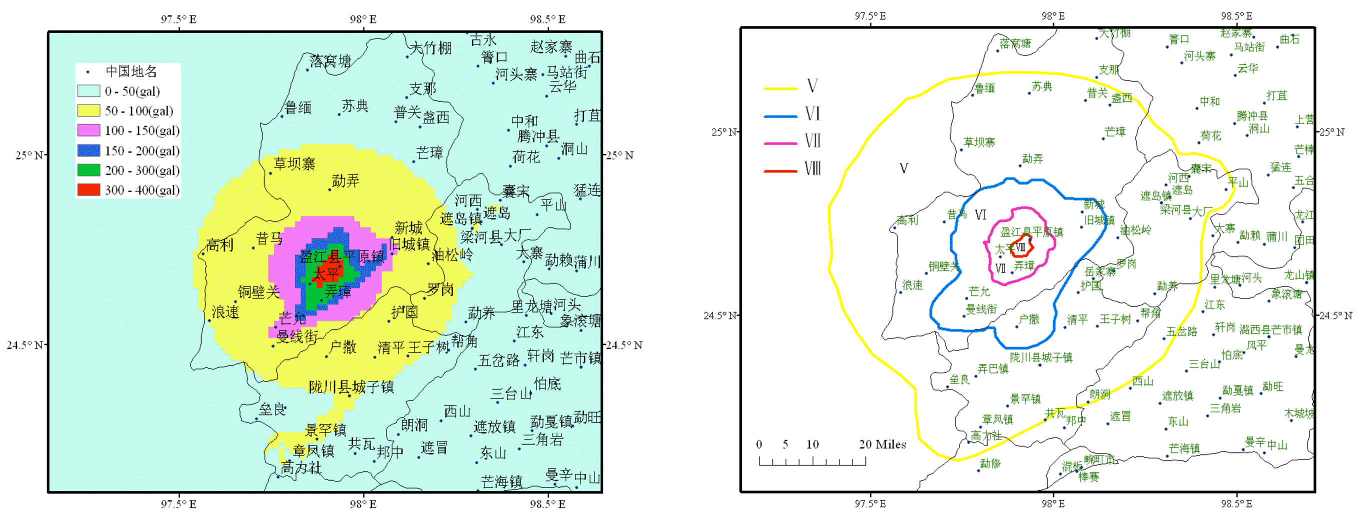

Fig.12 Ground motion and seismic intensity for Yingjiang Earthquake estimated by ShakeMap

(2) Initiating a batch of Urban ShakeMap System

With the lack of digital strong motion stations, most of central city in China, learned the lessons of Wenchuan Earthquake, plan to install a dense strong-motion network around the city. In Law of the People's Republic of China on Protecting Against and Mitigating Earthquake Disasters, Article 31 mentions that the central government supports the building of the national rapid earthquake intensity release system. To offer timely and effective support for the decision-making of government in case of earthquake emergency, many cities in China, such as Chengdu, the Provincial capital of Sichuan which suffered the Wenchuan Earthquake, have initiated the construction of a rapid earthquake intensity release system. This system consists of one data management center and 67 real-time free-field strong motion stations, and the average distance of stations is about 14km, that is to say 0.54 station within 100km^2. All of the stations are equipped with sensors coupled with 24-bit digital recorders. Strong-motion stations have been sending data to the acquisition center in real-time mode using TCP/IP over links. The data recorder is configured to continuously transmit the stream data and locally trigger and save event data to the compact flash cards providing backup in case of telemetry failure. Time synchronization is achieved at each digitizing/recorder unit using GPS receivers. The real-time connections allow the use of strong-motion data for the generation of shake maps. Right now more than 10 central cities are planning or building the similar system. Right now, the local networks don't usually share the strong motion data with the national network and those system could be treated as the part of national strong motion network in the future and should integrate together to serve the country well.

(3) Earthquake Early Warning System

With the wide dynamic range of accelerograph, and advanced data-acquisition and data transmission technologies, earthquake warning system will become the core infrastructure of a prototype. After an earthquake occurs, earthquake early warning system could immediately processes the observational data and quickly announces the information on epicenter, magnitude to the public through the media as well as to the disaster prevention organizations. The construction of the EEW system for Beijing capital region was starting by applying the seismological observations and velocity seismometer signals which are continuously transmitted to the data center. Beijing capital region has transited from testing mode to testing operation mode and has provided an internal prototype of the early warning service (Peng, H.S., *et al*., 2011). The development of an EEW system based on the strong motion and seismological network will merge in Chinese 11th-five-years plan, In National earthquake Public Service Project, two EEW systems will be set up and one is still in Beijing capital region which tries to use both seismological network and strong motion network, the other is located in Lanzhou, the capital city of Guanshu Province of China and each region will consist of more than 80 station.

5 CONCLUSIONS

National Strong Motion Observation Network System (NSMONS) of China which has been played an important role in earthquake mitigation, especially during the Great Wenchuan Earthquake and serial destructive earthquakes, is introduced. The strong-motion data are fundamental for earthquake engineering studies such as advanced structural analyses, seismic hazard evaluation, site effects and calibration of ground motion attenuation relationships and we should gather and update those data efficiently and service the engineering requirement so that we can engage our work to the stakeholders of public affairs more closely. It has provided the high-quality strong motions recordings could improve the earthquake design criteria for buildings and other engineering infrastructure and also provide the basic information for studying the earthquake source mechanisms as well as seismic wave propagation and local site effects.

China is a huge country and the strong-motion network in China is very sparse, and to build more strong motion stations to improve the performance of strong motion task is still a great challenge. More and more local governments and enterprises have their own strong motion observation system, measurements also should be taken to merge them with NSMONS to serve the whole country better.

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REFERENCES

China National Strong Motion Center [2009a]. "*Report on strong earthquake motion records in China*, *Vol.13, No.1*". Earthquake Publishing Press, Beijing, China.

China National Strong Motion Center [2009b]. "*Report on strong earthquake motion records in China*, *Vol.14, No.1*". Earthquake Publishing Press, Beijing, China .

China National Strong Motion Center [2011]. "*Report on strong earthquake motion records in China*, *Vol.15, No.1*". Earthquake Publishing Press, Beijing, China.

Gao, G., H.Y., Yu and S.Y., Li [2001]. "Strong Ground Motion Observation for China mainland", World Earthquake Engineering, Vol.17, No. 4, pp. 13-18 (in Chinese).

Gao, M.T. [2003]. "New national seismic zoning map of China", Acta Seismologica Sinica, Vol.16, No. 6, pp. 639-645.

Li, X.J., Z.H., Zhou, M., Huang, *et al*. [2008a]. "Preliminary Analysis of Strong-Motion Recordings from the Magnitude 8.0 Wenchuan, China, Earthquake of 12 May 2008", Seismological Research Letters, Vol.79, No.6, pp. 844-854.

Li, X.J., Z.H., Zhou, M., Huang, *et al*. [2008b]. "Strong motion observations and recordings from the great Wenchuan Earthquake", Earthquake Engineering and Engineering Vibration, Vol. 7, No.3, pp. 235-246.

Li, S.Y., X., Jin and Q. F., Liu [2003]. "Prospect of strong motion observation in China". Journal of Earthquake Engineering and Engineering Vibration, Vol. 23, No. 2, pp. 1-7 (in Chinese).

Peng, H.S., Z.L.,Wu, Y.M., Wu, *et al*. [2011]. "Developing a prototype earthquake early warning system in the Beijing capital region", Seismological Research Letters, Vol. 82, No. 3, pp. 394-403.

Wang, F. and P., Hu [2006]. "Research on the Structural Seismic Response Observation System in Chinese Mainland", Recent Developments in World Seismology, No. 329, pp. 8-13 (in Chinese).

Xie, L. and S., Yu [1982]. "*Strong Ground Motion Observation and Analysis Principle*". Earthquake Publishing Press, Beijing, China.