Construction and development of China digital seismological observation network^{*}

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Abstract

The seismological observation system in China has experienced rapid development over the Tenth Five-year Plan period. China Earthquake Administration (CEA) has completed the establishment of China digital seismological observation network. CEA has accomplished analog-to-digital conversion of the existing seismological observation systems and set up a number of new digital seismic stations. This indicates full digitization of seismological observation in China. This paper presents an overview of the scale, layout principle and major functions of the updated national digital seismograph network, regional digital seismograph network, and digital seismograph network for volcano monitoring and mobile digital seismograph networks in China.

Key words: seismograph network; seismic array; broadband

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Introduction

China began to establish its digital seismograph network in the 1980s. In May, 1983, China Earthquake Administration (CEA) and the United States Geological Survey (USGS) began an overall design of China Digital Seismograph Network (CDSN), and by 1986, the first national-level digital seismograph network in China had come into existence, which comprised nine digital seismic stations (Beijing, Sheshan, Mudanjiang, Hailaer, Ürümqi, Qiongzong, Enshi, Lanzhou and Kunming), a CDSN maintenance center and data management center. Lhasa and Xi'an digital seismic stations were set up respectively in 1991 and 1995, and came into the seismograph network. CEA and USGS jointly carried out remodeling of CDSN between 1993 and 2001, making its hardware and software systems in conformity with the technical regulations of Global Seismograph Network (GSN) established by the Incorporated Research Institutions for Seismol-

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ogy (IRIS). Now CDSN has become one of the major partners of GSN (ZHOU *et al.*, 1997).

Supported by the central and local governments, CEA began to establish China digital seismological observation system in 1996. According to the principle of uniform distribution of seismic stations while ensuring intensive observation in some key areas, the observation system was designed to consist of national digital seismograph network, regional digital seismograph networks and mobile digital seismograph networks (ZHUANG *et al.*, 2003). It was completed and began operation at the end of 2000. The national digital seismograph network has 48 seismic stations equipped with very-broadband (VBB) seismographs, among which 37 use exclusively China-made seismographs and 10 are updated from the original Sino-US cooperative stations. All of the seismic stations perform 24-bit data acquisition and the waveform data are real-time transmitted to the center of national digital seismograph network *via* a satellite network. There are altogether 20 regional digital seismograph networks in China, which have 267 digital seismic stations performing 16-bit data acquisition. The waveform data are real-time transmitted to the centers of local seismograph networks. The mobile digital seismograph networks have 100 portable seismographs, which are exactly of the same type as those in the regional networks. Between 1999 and 2001, the Capital-circle Digital Seismograph Network (covering Beijing Municipality, Tianjin Municipality and Hebei Province) for real-time data transmission was established, which has 107 seismic stations performing 24-bit data acquisition. The national, regional and Capital-circle digital seismograph networks have gone into full operation since 2002 and outputted a vast amount of observational data.

The establishment of China's digital seismological observation network was launched by CEA in 2003, and by the end of 2007, an updated digital seismological observation system had come into existence, which consists of national digital seismograph network, regional digital seismograph networks, digital seismograph networks for volcano monitoring and mobile digital seismograph networks.

1 National digital seismograph network

The national digital seismograph network is an earthquake monitoring network with uniformly distributed seismic stations all over China (Figure 1). The network consists of 152 seismic stations equipped with ultra-broadband (UBB) and very-broadband (VBB) seismometers, two small-aperture seismic arrays, one national earthquake network center and one data backup center for the national digital seismograph network.

1.1 National digital seismic stations

The 152 national seismic stations (including the seven stations outside China) include 48 primary stations and 104 newly built ones equipped with VBB digital seismographs. The average distance between seismic stations is about 250 km, except in Qinghai-Tibet Plateau. By the end of 2007, 145 seismic stations inside China had been set up. The national digital seismic stations are equipped with UBB and VBB seismometers and have relatively better sites for observation, most have caves in mountains.

Of the 145 seismic stations inside China, 10 CDSN stations are equipped with STS-1 VBB seismometers, STS-2 broadband seismometers, GS-13 short-period seismometers and FBA-23 acceleration seismometers, Lanzhou station use China-made CTS-1 VBB seismometer, 16 stations use China-made JCZ-1 UBB seismometers and 118 use CTS-1, KS2000 and CMG-3ESPCB (borehole) VBB seismometers.

Figure 1 Distribution of national digital seismic stations

JCZ-1 features a flat velocity response from 360 s to 20 Hz and a flat acceleration response from 360 s to 3000 s; CTS-1, KS-2000 and CMG-3ESPCB all feature a flat velocity response from 120 s to 50 Hz; STS-1 has a flat velocity response from 360 s to 8.5 Hz; STS-2 has a flat velocity response from 120 s to 40 Hz and GS-13 has a bandwidth of 1 s~30 Hz.

Besides, two ocean bottom seismic observatories have been built, one in Bohai Sea and the other in East China Sea, for accumulating experiences for future ocean bottom seismic observation.

1.2 Small-aperture seismic arrays

In order to improve earthquake monitoring in the western parts of China, two small-aperture seismic arrays have been established, one in Naqu, Tibet (Figure 2b), and the other in Hetian, Xinjiang (Figure 2a). Each of the round-shaped arrays consists of nine sub-stations: one in the center,

Figure 2 Distribution of sub-stations of seismic arrays
(a) Hetian array; (b) Naqu array

three in the inner circle (500 m in radius) and five in the outer circle (1 500 m in radius). Geometrically, the sub-stations are almost uniformly distributed.

The central stations of the two arrays use CTS-1 VBB seismometers. The other stations of Naqu use DS-4D and those of Hetian use CMG-40T-1 short-period seismometers. DS-4D and CMG-40T-1 both have a flat velocity response from 2 s to 50 Hz.

The sub-stations are all equipped with 24-bit data collector, which facilitates IP data transmission and local storage. The real-time waveform data of the sub-stations are respectively transmitted to the earthquake network centers of Tibet Autonomous Region and Xinjiang Uygur Autonomous Region and forwarded to the national earthquake network center.

1.3 National Earthquake Network Center

Located in China Earthquake Network Center (CENC), the National Earthquake Network Center (NENC) undertakes the responsibilities of seismic data aggregation and transmission, rapid earthquake information release, earthquake catalogue, seismic data management and service, supervision and technical management of seismograph networks.

NENC is capable of attaining real-time aggregation of continuous waveform data from the 145 national digital seismic stations, two small-aperture arrays and six seismic stations for volcano monitoring. It can also attain quasi real-time data aggregation from 792 regional digital seismic stations and quasi real-time aggregation of seismic waveform data from 77 GSN stations *via* USGS/NEIC. The regional earthquake network centers are capable of attaining quasi real-time aggregation of waveform data from some of the seismic stations of nearby regional seismograph networks *via* NENC, with a time delay no longer than 5 s. This has effectively solved the problem of rapid earthquake information release and earthquake catalogue based on seismic data from outlying seismic stations or seismic stations outside the network.

Based on data from both national and regional seismic stations, NENC is capable of detecting $M_L 2.5$ earthquake events in most areas on the Chinese mainland. In most of North China, north-eastern China, central China, some parts of northwestern China and eastern coastal areas of China, it can even detect events of $M_L 2.0$; in the key areas for earthquake surveillance and protection and in heavily populated major cities, it can detect events with a magnitude as small as $M_L 1.5$. The combined use of GSN and NENC data greatly increased the speed of information release and positioning accuracy of earthquakes in China's border area or outside China. NENC can release first information on the epicenter of an $M_S \geq 4.5$ earthquake inside or in the vicinity of China within 10 minutes and accurate information of the epicenter within 20 minutes. It can release information on an $M_L \geq 3$ event within a regional digital seismograph network in no more than 10 minutes and the information on focal mechanism solution of an $M_S \geq 4.5$ event inside China in no more than 30 minutes.

NENC has set up a seismic data management and service system, which boasts fairly advanced technology, complete function and need satisfaction for various users. Users can download seismic waveform data, earthquake catalogue, seismic phase data and focal mechanism data of the national digital seismograph network and regional digital seismograph networks *via* <http://data.earthquake.cn> and <http://www.csndmc.ac.cn> (LIU *et al*, 2007).

To ensure the safety of NENC data, a data backup center for national digital seismograph networks has been set up in the Institute of Geophysics, CEA (known as IGPCEA). It undertakes online backup of the real-time data and quasi real-time data collected by NENC and, relying on the advantage of IGPCEA in seismology and Earth's interior physics, it has constructed

high-performance and high-reliability seismic data platform and computing platform through system integration, thus facilitating product development and computation with respect to earthquake science research and other researches for various sectors of the country.

2 Regional digital seismograph network

By the end of the Tenth Five-year Plan period, a total of 31 regional digital seismograph networks have been set up, which are responsible for monitoring regional seismic activities. The 685 seismic stations belonging to the regional networks almost cover earthquake-prone areas, economically developed areas and densely populated areas in China (Figure 3). At present, each of the 31 provinces, autonomous regions and municipalities on the Chinese mainland has a regional digital seismograph network. The total number of regional seismic stations on the Chinese mainland has now reached 792, including the 107 seismic stations already built in the Capital Area. The average distance between regional seismic stations is as short as 30~60 km in most provinces and around 100~200 km in Xinjiang and Qinghai-Tibet Plateau.

Figure 3 Distribution of new regional seismic stations

Most of the regional seismic stations use broadband seismometers and short-period borehole seismometers and observations are carried out either on the surface or in boreholes. The broadband seismometers include 60 s~50 Hz CMG-3ESPC, CMG-3ESPCB, BBVS-60 and KS-200M, the short-period ones are 2 s~50 Hz JDF-2, FSS-3DBH and FSS-3B, all having a flat velocity response.

Major undertakings of the regional seismograph networks include ① rapid information release about earthquakes within their respective networks: they release first information of an $M_L \geq 3$ event in no more than three minutes and final information in no more than 15 minutes; ② earth-

quake monitoring: they are capable of detecting $M_L 2.5$ events within their networks and $M_L 1.5$ events in the key areas for earthquake surveillance and protection, in heavily populated major cities and in eastern coastal areas; ③ compiling reports of seismograph networks for earthquake forecast and scientific research.

3 Digital seismograph network for volcano monitoring

There are altogether 33 seismic stations in six digital seismograph networks for volcano monitoring across China. Among these stations, 10 are in the seismograph network for Changbaishan Volcano, Jilin Province, four for Longgang Volcano, Jilin Province, eight for Tengchong Volcano, Yunnan Province, three for Wudalianchi Volcano, Heilongjiang Province, four for Jingpohu Volcano, Heilongjiang Province and four for Qiongbai Volcano, Hainan Province.

The seismic stations for volcano monitoring, equipped with 60 s~40 Hz broadband seismometers or 2 s~50 Hz short-period seismometers, can fulfill unattended duty, and operate by network monitoring and quasi real-time data transmission. They are capable of detecting $M_L 1.0$ seismic events in the six volcano areas.

4 Mobile digital seismograph network

The mobile digital seismograph networks, equipped with 800 seismometers, include mobile networks for earthquake emergency response and a portable array for seismic detection.

4.1 Mobile network for earthquake emergency response

Mobile networks are mainly used for foreshock observation before large earthquake and aftershock monitoring. They contribute to the study of regional seismic activity and earthquake prediction by intensive observation before large earthquake, high-precision hypocenter location and continuous monitoring of seismic activities in critical earthquake risk areas. After large earthquake, the networks are used for aftershock monitoring and recording, providing reference for the judgment of earthquake tendency and accumulating essential data for further study of source characteristics and initiation process of earthquakes.

There are altogether 19 mobile seismograph networks for earthquake emergency response. The networks have 200 portable digital seismographs, which are either 60 s~40 Hz broadband seismometers or 2 s~50 Hz short-period seismometers.

4.2 Portable array for seismic detection

The portable array for seismic detection can carry out observation in a study area by various means and on various scales according to different scientific purposes. In some cases, the distance between seismic stations can be no more than several kilometers. High resolution seismic records from the portable array can yield corresponding high resolution results. When applied to investigations concerning hypocenter location, focal mechanism solution, rupture process of earthquakes and seismic imaging, these high resolution seismic records can help improve greatly precision of the research findings. As an important means for high resolution exploration of Earth's interior, portable array can not only be used in seismological research, but has a wide application in earth science research. The general goal for the construction of the array system is to build an international level portable array with a strong support system, which can serve as an observation platform and data service platform for earthquake science research.

The portable array system consists of six subsystems: portable instrument system, monitoring and management system of an observation unit, vibroseis system, technical support system for

mobile observation, data center for mobile observation and experiment field for mobile observation. The key part is the instrument system, which comprises 600 GÜRALP seismometers, 600 REFTEK-130B data collectors and 600 solar power systems. These instruments include 10 VBB (120 s~40 Hz) CMG-3T seismographs, 500 broadband (60 s~40 Hz) CMG-3ESPC portable seismographs and 90 short-period (2 s~50 Hz) CMG-40T seismographs. The portable array system is functioning under the care of IGPCEA.

5 Conclusions

With the establishment of China digital seismological observation network, China's seismological observation system has achieved analog-to-digital conversion, thus, a digital seismological observation system has come into existence, which consists of the national seismograph network, 31 regional seismograph networks, six seismograph networks for volcano monitoring and mobile seismograph networks. This symbolizes full digitization of China's seismological observation. During the eleventh Five-year Plan period, layout of the seismograph networks will be optimized, seismic stations be set up in previously unmonitored areas and ocean experiments be enhanced, so that a more rationally designed seismological observation system will be established, which covers the whole of Chinese mainland and its surrounding sea areas. The system will have the capability of monitoring and detecting such seismic background fields as seismicity image, normal geophysical field and subsurface structure all over Chinese mainland and the offshore areas. It will also be capable of data generation and data processing of the seismic background fields. Thus, China's future seismological observation system will provide more plentiful data services for earthquake prediction, earth science research, national economic development and the public society.

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