Status Quo of Lanzhou Earthquake Early Warning System and Analysis of Its Key Technical Indicators

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Abstract. The composition, network configuration and system operation condition of Lanzhou earthquake early warning system are introduced in details, and the factors influencing the early warning performance are discussed. Then, in combination of the status quo of system, the key technical indicators are analyzed, and the distribution map of consumed time for earthquake early warning is drawn. The result indicates that the average distance among stations in observation network is large, which casts an obvious influence on the time validity of early warning. Under the set conditions, the radius of blind zone ranges between 30.3km and 39.2km, and the early warning time increases as the epicentral distance enlarges. In addition, the radius of blind zone is influenced by the focal depth. Furthermore, influenced by the station distribution and density, the distribution of consumed time for earthquake early warning is extremely uneven and characteristic of obvious regional difference.

1. Introduction

Based on the fundamental principle that the propagation velocity of P-wave is higher than that of destructive S-wave and surface wave and that the propagation velocity of electromagnetic wave is far higher than that of earthquake wave, earthquake early warning is to utilize the real-time transmission earthquake observation network configured in the early warning target area or potential seismic source zone to determine the basic earthquake parameters and estimate the possible influential field distribution in a very short period after the earthquake occurs as well as then timely send out earthquake alarms and take corresponding emergency handling measures before the destructive earthquake wave reaches the early warning target area, which can effectively alleviate the property loss and personal casualties caused by the earthquake\cite{1-4}.

The conception of earthquake early warning was firstly proposed by Dr.Cooper after the earthquake in San Francisco, US in 1868. He assumed to configure earthquake observation stations in Hollister District 100km away from San Francisco, where the earthquake activity is very high. Therefore, once an earthquake occurs, the propagation time difference between electromagnetic wave and earthquake wave can be utilized to sound the alarm in the City Hall of San Francisco in a very short time after the earthquake so that people can take some corresponding emergency rescue measures to reduce casualties \cite{5}. However, this conception was not realized due to limitations of tech level at that time. In recent 20 years, with the quantum leaps in computer technology, data transmission processing technology, earthquake monitoring instruments and earthquake observation method, the conception of Dr.Cooper is gradually evolving into a reality. Currently, in some countries
and regions frequent of earthquakes, such as Japan, Mexico, Turkey and Taiwan, multiple earthquake early warning systems aimed at specific facilities, single city or even bigger region, have been established, and remarkable disaster relief effect has been achieved in practical operation; US, Italy and South Korea also have actively carried out relevant real-time tests on earthquake early warning system[6-9].

In mainland China, the relevant research and construction of earthquake early warning started relatively late. In the construction periods of 9th and 10th Five-Year Plan, a large batch of earthquake observation stations were built by China Earthquake Administration and a series of relevant scientific research projects on construction of earthquake early warning system were organized and executed[10-12]. In recent years, relying on its own tech advantages, Fujian Earthquake Agency has built a complete provincial earthquake early warning system; China Earthquake Administration has authorized the execution of China Earthquake Background Field Exploration Project and National Earthquake Social Service Project, and constructed two demonstrative earthquake early warning systems in Beijing and Lanzhou. The construction and operation of these early warning systems have accumulated excellent experience for the development of earthquake early warning in China. Currently, the National Earthquake Intensity Quick Reporting and Early Warning Project has been initiated across a national range and the macroscopic exploration and selection for observation stations have been carried out comprehensively. Before China officially starts the construction of large-scale earthquake early warning systems, it is of great significance to analyze and evaluate the status quo of current early warning network and its capability. Only in this way can we find the corresponding insufficiencies and specify the improvement direction. To address this problem, Lanzhou earthquake early warning system is adopted as research object in this paper; then, in combination of its current network configuration and system operation, the key technical indicators influencing its early warning efficiency is analyzed deeply; next, corresponding improvement directions and suggestions are proposed in the hope of providing a certain reference to the future construction of earthquake early warning system in China.

2. Status quo of Lanzhou earthquake early warning system

As a regional earthquake early warning system specially targeted towards Lanzhou, Lanzhou earthquake early warning system provides earthquake early warning and intensity quick reporting information for Lanzhou in medium or large earthquakes occurring in Lanzhou and its surrounding areas. This system consists of early warning observation network, data processing platform and information distributing platform. Specifically, early warning observation network obtains the original data of earthquake early warning information and mainly accomplishes the real-time detection, transformation and digitization of earthquake signals as well as data packing, communication control and transmission; as the core of the whole system, data processing platform mainly accomplishes real-time monitoring over the operation condition of early warning observation network, identifies and pre-processes the earthquake events, quickly measures the earthquake parameters and outputs earthquake early warning and intensity quick reporting information; as the information terminal of the whole system, information distributing platform faces directly towards the service objects and distributes the early warning information through information distributing terminals and alarming devises. Fig.1 shows the overall structure of above system.
2.1 Configuration of early warning observation network

The observation network of Lanzhou earthquake early warning system consists of strong motion observation network and seismometry observation network. The monitoring range can cover the entire Gansu and some areas in neighboring provinces. Fig.2 shows the configuration of the whole early warning observation network. Specifically, the strong motion observation network consists of 80 strong motion observation stations, which are centered around Lanzhou and extend outwards in a ring shape. It includes 54 strong motion stations located in Gansu, 15 stations in Qinghai and 11 stations in
Ningxia, and the farthest station is 375km away from Lanzhou. The seismometry observation network consists of 83 seismometry observation stations, which are distributed in a mesh form, including 47 stations in Gansu and 36 data sharing stations in neighboring provinces. In the aspect of instrument category, all the strong motion observation stations adopt the configuration of REFTEK-130REN data collectors and SLJ-100 accelerometer. In addition, the data collectors adopted by seismometry observation stations are mainly EDAS-24 Series, CMG-DM24 and SMART-24, and the sensors are mainly BBVS-60, BBVS-120, CMG-3EMPC and CTS-1. All the above instruments adopt the communication method of real-time transmission by optical fiber.

2.2 Operation status quo of early warning system
Currently, the data processing platform in Lanzhou earthquake early warning system adopts automated processing software, which can identify and process the earthquake events quickly. Within several seconds after the first observation station is triggered, the platform can present the initial earthquake three-element information as well as the early warning time and predicted intensity of early warning target area; within 5-6mins after the earthquake, relevant intensity quick reports, including the instrument intensity figure in the earthquake area and PGA isoline figure, are outputted. In addition, the information distributing platform adopts special database and information reception terminals, which can realize the automatic reception and distribution of early warning information. The information reception terminals currently adopted include digital VHF LED display screen, smart radio, digital VHF loudspeaker and cellphone APP. Since the operation of Lanzhou earthquake early warning system, it has successfully outputted early warning and intensity quick reporting information in several earthquakes in Gansu and its neighboring regions.

3. Key technical indicators of earthquake early warning

3.1 Earthquake early warning modes
According to the difference in working modes, the earthquake early warning can be divided into on-site early warning, off-site early warning and mixed early warning modes. The on-site early warning mode refers to configuring stations in early warning target area and utilizing the arrival time difference between the first-arrival wave (generally P-wave) and the late-arrival destructive wave (S-wave or surface wave) for early warning. Its merits include single target and simple configuration while its shortcomings include little usable information, low accuracy and short early warning time. Compared to on-site early warning mode, off-site early warning mode adopts traditional earthquake monitoring method. In this mode, earthquake observation stations are densely configured in potential seismic source area, which are utilized to record the signals (P-wave or S-wave) to determine the basic earthquake parameters, thus it can estimate the ground motion in early warning target area and send alarms to potential earthquake destruction area. The merits of this mode include long early warning time, rich usable information and accurate earthquake parameter measurement while its shortcomings include the necessity of support from heavily-dense observation network, massive investment and complex system structure[13].

In the early development stage of earthquake early warning, the majority of early warning systems adopt on-site early warning mode due to limitations of observation technology and station density. As the development of observation instruments and data transmission technology as well as station density advance, the difference between on-site and off-site early warning is gradually diluted. The mixed early warning mode combining above two modes is becoming more popular. This mode can integrate the merits of on-site and off-site early warning and make full use of current network resources, but the accompanying problem is that its technical system has become more complex.

3.2 Time validity of earthquake early warning
The time validity of earthquake early warning is generally represented by early warning time and blind zone[13]. The early warning time refers to the time left for the early warning object to take emergency handling measures after it receives the early warning information and before the destructive
earthquake wave arrives. The length of early warning time reflects the efficiency of an earthquake early warning system and is directly related to the distance from the early warning object to the earthquake source and the time it takes to distribute early warning information (hereafter called consumed time of early warning). In addition, the early warning blind zone refers to the propagation area of destructive wave (generally S-wave) when the early warning information are distributed. The early warning information cannot be timely delivered to the objects inside the blind zone and thus the early warning efficiency is lost. The range of blind zone is decided by the consumed time of early warning and directly reflects the efficiency of earthquake early warning system. The smaller the blind zone is, the higher the early warning efficiency will be.

Generally, the consumed time of early warning includes the time for P-wave to propagate to stations, data transmission delay, earthquake parameter calculation time, information distribution delay and response delay of reception terminal[14]. Specifically, the time for P-wave to propagate to station is closely related to the focal depth, station density and location of earthquakes; data transmission delay is influenced by instrument and network performance; earthquake parameter calculation time is related to calculation speed and performance of processing software; distribution delay of early warning information and response delay of reception terminal are decided by the software & hardware performance of distributing system and network condition.

4. Analysis of key technical indicators in Lanzhou earthquake early warning system

4.1 Basic parameters of Lanzhou earthquake early warning system

Lanzhou earthquake early warning system is a regional earthquake early warning system adopting off-site early warning mode. It takes Lanzhou as its major early warning object and provides it with earthquake early warning and intensity quick report service. The whole system contains 163 observation stations (as shown in Fig.2) and the average station distance is about 70-80km. In addition, the stations are relatively densely distributed in the east but scarcely distributed in the west. There are fewer observation stations in northwestern Gansu, and the average station distance is correspondingly larger. By comparison, there are relatively more observation stations in mid-eastern Gansu, namely Lanzhou and its surrounding areas, and the station distance is correspondingly shorter. Specifically, 116 observation stations are within 300km away from Lanzhou (including 76 strong motion stations and 40 seismometry stations), and the average station distance is 49.4km. In addition, according to the statistical operation data of Lanzhou earthquake early warning system since its establishment, the transmission delay of the majority of observation stations is within 2s, and the earthquake parameter calculation time is about 5-10s. Considering currently early warning information has not yet been distributed to the public officially, the distribution delay of early warning information and response delay of reception terminal are not considered in this paper.

4.2 Time validity analysis of Lanzhou earthquake early warning system

The theoretical early warning time of Lanzhou earthquake early warning system, \( T_w \), can be expressed as:

\[
T_w = T_s - T_{p,1} - T_d - T_{pr} = \sqrt{\Delta_x^2 + h^2} \frac{v_s}{v_p} - \sqrt{\Delta_s^2 + h^2} - T_d - T_{pr}.
\]

where, \( T_s \) is the time it takes for S-wave to arrive at the early warning object, \( T_{p,1} \) is the time it takes for P-wave to arrive at the station closest to the epicenter, \( T_d \) is the data transmission delay, \( T_{pr} \) is the earthquake parameter calculation time, \( \Delta \) is the epicentral distance of early warning object, \( \Delta_s \) is the epicentral distance of the station closest to the epicenter, \( h \) is the focal depth, \( v_s \) and \( v_p \) are the propagation speeds of S-wave and P-wave.

When \( T_w \leq 0 \), there is no early warning time theoretically. In other words, the early warning objects close to the earthquake source have no time to take emergency handling measures before the
destructive earthquake wave arrives due to short epicentral distance, which means they locate in the early warning blind zone.

In this paper, assuming an earthquake occurs at a certain point within 300km away from Lanzhou, considering that the average station distance within this region is 49.4km, we simply assume that the longest epicentral distance of the station closest to the epicenter is 24.7km, namely $0 \leq \Delta \leq 24.7$ km; in addition, we adopt the single-layer crust model in Gansu to calculate the arrival time of earthquake wave[15], where $v_s=3.57$km/s and $v_p=6.10$km/s; besides, it is assumed that the focal depth $h=15$km, $T_p=2$ s and $T_{pr}=5$ s.

When $\Delta=0$km, namely under idea condition, there is one observation station right at the epicenter, assuming $T_w=0$, we can calculate that $\Delta=30.3$km, that is, the radius of early warning blind zone is 30.3km. When $\Delta=24.7$km, namely that the earthquake occurs right at the middle of two observation stations, at this case we can calculate that the radius of blind zone is 39.2km. So it can be concluded that for this set earthquake, the radius of blind zone in Lanzhou earthquake early warning system ranges between 30.3km and 39.2km.

In addition, we assume that $\Delta=10$km and thus can calculate the change to early warning time $T_w$ with the epicentral distance of early warning object (as shown in Fig.3). It can be seen from Fig.3 that under this setting, the radius of early warning blind zone is 32.2km. When the epicentral distance is 50km, the early warning object has 4.7s early warning time; as the epicentral distance increases, the early warning time is gradually increasing; when the epicentral distance reaches to 100km, the early warning object can obtain 18.4s early warning time.

Likewise, we can draw the changing curve of radius of blind zone with focal depth when $\Delta=10$km (as shown in Fig.4). It can be seen from Fig.4 that when the focal depth ranges between 0 and 30km, the change to radius of blind zone is not obvious and the radius maintains above 30km; when the focal depth exceeds 30km, as the depth increase, the radius of blind zone gradually decreases; when the focal depth increases to 61.4km, the radius of blind zone is 0km, which indicates that at this time the early warning object at the epicenter can also receive the early warning information. Considering that the focal depth of earthquakes in Gansu is mainly between 5km and 20km, therefore, the radius of blind zone in this region is commonly over 30km.

![Figure 3](image-url)

**Figure 3.** The curve of early warning time.
4.3 Analysis on consumed time of early warning

The research area ranges from 32°N to 43°N and from 93°E to 109°E, which is just surrounding Gansu province, and then we discretize it into grids based on 0.1°*0.1° unit element. Assuming that one earthquake occurs in each grid point (the focal depth is set as 15km), the system starts calculating, processing and outputting early warning information after the station closest to the epicenter is triggered, and the data transmission delay $T_d = 2s$, the calculation time $T_{pr} = 5s$. Thus, under the
current network configuration of Lanzhou earthquake early warning system, the distribution of consumed time of early warning in this area is shown in Fig.5. It can be seen from the figure that the consumed time of early warning is closely related to station distribution and density. The closer the area is to the observation station, the shorter the consumed time will be; the overall consumed time of early warning is correspondingly shorter in areas with higher station density. Based to this influence, the distribution of consumed time of early warning in Gansu is extremely uneven and has obvious regional difference. The shortest consumed time is about 9.0s while the longest is about 40.0s; the overall consumed time is relatively shorter in the mid-eastern region and longer in the northwestern region.

5. Conclusion and discussion
Earthquake early warning system is an enormous and complex project. The deficiency and insufficiency of any link will influence its overall early warning efficiency. The length of early warning time and the size of blind zone are the key to determine if it can play its role in earthquake prevention and disaster reduction. It can be found by the calculation and analysis in the previous sections that:

(1) The average station distance in the observation network of Lanzhou earthquake early warning system is relatively large, which severely influences the time validity of early warning. In mid-eastern Gansu where there are relatively more stations, the average station distance reaches about 50km; in northwestern Gansu, the average station distance is greater. In addition, data transmission and processing delay will cast quite an influence on the early warning time and blind zone radius. In the future, we need to constantly construct more observation stations to improve station density, optimize network configuration and minimize the data transmission and processing delay. Thus, the early warning efficiency of current system can be given to its full play.

(2) Under the conditions set in this paper, the radius of blind zone in Lanzhou earthquake early warning system ranges between 30.3km and 39.2km; the early warning time increases as the epicentral distance of early warning object enlarges; when the epicentral distance is 100km, the early warning time is 18.4s. The research result also indicates that the radius of early warning blind zone is influenced by the focal depth, which changes slightly when the focal depth ranges between 0 and 30km, and basically maintains above 30km; but when the focal depth exceeds 30km, the radius of blind zone is negatively proportional to the focal depth, as the depth increases, the radius will gradually reduce. Considering that the focal depth of the major earthquakes in Gansu is between 5km and 20km, the common radius of blind zone in this region is above 30km. In addition, it is found that due to the influence of station distribution and density, the distribution of consumed time of early warning is extremely uneven in Gansu and has obvious regional difference.

(3) In the calculation and analysis in this paper, the data transmission delay and earthquake parameter calculation time are set as 2s and 5s respectively; due to limitations of network status and waveform quality in working practices, the actual consumed time might be higher than above values. Secondly, the idea of starting earthquake parameter calculation and processing after one station is triggered is adopted in this paper; but in actual application, to ensure the accuracy and reliability of early warning information, the system will only start calculation and processing normally after three stations are triggered. In addition, the distribution delay of early warning information and response delay of reception terminal are not considered in this paper temporarily; however, when the early warning system formally distributes early warning information to public, it is difficult to avoid above delays in information transmission process. All the above factors will directly lead to the increase of consumed time of early warning and finally cause the early warning time to shorten and the blind zone to expand. Therefore, how to perfect the overall performance of system and improve the actual early warning efficiency will be key issues remaining to be solved in our future research.

The work in this paper is fundamental. The analysis of key technical indicators of Lanzhou earthquake early warning system assists us in better understanding the technical level and early warning efficiency of current system as well as exploring its deficiencies and insufficiencies, which
can provide necessary reference basis for promotion and application of early warning system in the future.

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