Analysis on Early Warning Capability of Gansu Earthquake Early Warning Stations Network

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Abstract. This paper briefly introduces the structure and network layout of Gansu Earthquake Early Warning Stations Network, and discusses the relationship of the effective early warning time and the radius of early warning blind zone with consumed time for early warning. Based on the layout of the current and future earthquake early warning stations network of Gansu, the consumed time for early warning under three stations triggered and six stations triggered is calculated and analyzed. In addition, the contour map of consumed time for early warning in Gansu is drawn. The results show that the effective early warning time is negatively correlated with consumed time for early warning, and the radius of the early warning blind zone is positively correlated with consumed time. And the consumed time for early warning of the future earthquake early warning stations network under three triggered stations and six triggered stations in Gansu is shortened by 29.24% and 37.13% compared with those of the current earthquake early warning stations network. After the completion of the Gansu Subproject, the effective early warning time will be increased and the radius of the early warning blind zone will be reduced, then the early warning capability in Gansu is to be greatly improved.

1. Introduction

Earthquake early warning as a new type of earthquake prevention and mitigation method has developed rapidly in recent years. It mainly uses the initial ground motion information recorded by seismic observation stations near the earthquake source to quickly determine the basic earthquake parameters and predict the influences of the early warning target area, and then timely send out earthquake warning information and take corresponding countermeasures before the destructive seismic wave arrives at the target area, thus effectively alleviate the property damage and casualties caused by the earthquake [1-2].

The conception of earthquake early warning was first proposed by Dr. Cooper after the earthquake in San Francisco, USA in 1868. With the quantum leaps of related science and technology in recent decades, the conception was gradually evolving into a reality. At present, earthquake early warning systems have been established in some countries and regions frequent of earthquakes such as the Japan Emergency Earthquake Early Warning System, the US Earthquake Alarms Systems, Mexico's SAS system, Taiwan's rapid reporting and early warning system, Istanbul's early warning system and Romania earthquake warning system [3-6]. In recent years, China Earthquake Administration has constructed two demonstrative earthquake early warning systems in Beijing and Lanzhou through the implementation of China Earthquake Background Field Detection Project and the National Earthquake Social Service Engineering Project [7].
Current earthquake early warning stations network in Gansu serves the Lanzhou earthquake early warning demonstration system which was constructed in 2014. The network is mainly composed of the 80 strong motion observation stations and 83 seismometry observation stations in Gansu and neighboring provinces. The future earthquake early warning stations network of Gansu will be based on the Gansu Subproject of the National Earthquake Intensity Quick Reporting and Early Warning Project that has been carried out comprehensively currently. But the early warning capabilities of the current and the future earthquake early warning stations network are not yet known. To address this problem, it is necessary to carry out scientific analysis and assessment of the overall performance and early warning capability of the Gansu earthquake early warning stations networks, and corresponding reference suggestions are provided for the future construction of the earthquake early warning system in Gansu.

2. Introduction of Gansu earthquake early warning stations network

2.1. Current earthquake early warning stations network
At present, the current earthquake early warning stations network serves the Lanzhou earthquake early warning system, and consists of 80 strong motion observation stations and 83 seismometry observation stations. All of observation stations adopt the optical fiber based real-time transmission and communication mode. The distribution of the current earthquake early warning stations network is shown in Figure 1.

2.2. Future earthquake early warning stations network
In the future, the Gansu earthquake early warning stations network will be based on the Gansu Subproject of the National Earthquake Intensity Quick Reporting and Early Warning Project (hereinafter referred to as the Gansu Subproject). The completed future earthquake early warning stations network will consist of 1,324 stations including 164 benchmark stations, 205 basic stations, 900 general stations, 54 strong motion observations station and Luqu seismometry observation station. The distribution of the 1,324 stations in the future earthquake early warning stations network is shown in Figure 2.
3. Early warning capability efficient
The early warning capability coefficient is generally represented by effective early warning time and early warning blind zone.

3.1. Effective early warning time
The effective early warning time refers to the time left for the early warning object to take emergency measures after receiving the earthquake early warning signal before the arrival of the destructive earthquake wave, which means the difference between the time spent by the S-wave to reach the early warning object and the time consumed for the earthquake early warning system to release the early warning information (referred to as consumed time for early warning) as shown in formula (1). In general, consumed time for early warning includes the time for the P-wave to spread to the stations, the data transmission delay, the calculation time of earthquake parameters, the early warning information release delay, and the response delay of receiving terminal [8] as shown in formula (2).

$$T_w = T_s - T_r = \frac{(\Delta g^2 + h^2)^{1/2}}{v_s} - T_r \quad (1)$$

$$T_r = T_p + T_d + T_{pr} + T_{rd} \quad (2)$$

Where, $T_w$ is the effective early warning time, $T_s$ is the time for the S-wave to reach the earthquake early warning object, $T_r$ is consumed time for early warning, $T_p$ is the time for the P-wave to spread to the stations, $T_{pr}$ is the calculation time of earthquake parameters after the stations are triggered, $T_d$ is the data transmission delay, $T_{rd}$ is the release delay of earthquake early warning information and the response delay of receiving terminal, $\Delta g$ is the epicenter distance of the earthquake early warning target area, $h$ is the focal depth and $v_s$ is the spread velocity of the S-wave.

3.2. Early warning blind zone
The early warning blind zone refers to the zone where the earthquake early warning information cannot be accessed before the destructive seismic wave arrives at the target area. The blind zone is the...
circle centered on the epicenter with the S-wave spread distance as the radius at the release of the earthquake early warning information.

When $T_w = 0$ in formula (1), $\Delta g$ is theoretically equal to the radius of the early warning blind zone, and the radius of the early warning blind zone $R_0$ can be obtained:

$$R_0 = \left( (v_s \cdot T_r)^2 - h^2 \right)^{1/2} \quad (3)$$

Therefore, the effective early warning time $T_w$ is negatively correlated with consumed time for early warning $T_r$, and radius of the early warning blind zone $R_0$ is positively correlated with consumed time $T_r$. Consumed time for early warning directly reflects the early warning capability of the earthquake early warning stations network. When consumed time for early warning decreases, the effective early warning time increases, and the radius of the early warning blind zone decreases. So, decreasing the consumed time is the key way to improve the early warning capability.

4. Analysis on consumed time for early warning

The single-layer crustal model in Gansu ($v_p = 6.10$ km/s, $v_s = 3.57$ km/s) is adopted, besides, it is assumed that the processing time $T_{pr}$ is 3s, and the transmission time $T_d$ is 2s. In addition, all the observation stations are 100% operating normally. The paper does not consider the release delay of early warning information and the response delay of receiving terminal.

The research area ranges from 32° N to 43° N and from 93° E to 109° E which is just surrounding Gansu province. The area is discretized into uniform grids at an interval of 0.1°*0.1°. Three or six triggered stations means after the earthquake occurred, the P-wave propagated to the three or six stations closest to the earthquake source, and the P-wave data was recorded at all three or six stations. Under the above conditions, it is assumed that an earthquake occurs at each grid point (the focal depth $h$ is 15km). Consumed time for early warning for the earthquake early warning system to release the early warning information under three triggered stations and six triggered stations is calculated, and then the contour maps of consumed time for early warning are drawn.

4.1. Analysis on consumed time for early warning in current earthquake early warning stations network

Under the set conditions, the contour maps of consumed time for early warning under three triggered stations and six triggered stations of the current earthquake early warning stations network are shown in Figures 3 and 4.

![Figure 3](image3.png)  
**Figure 3.** Contour map of consumed time under 3 triggered stations in current stations network.

![Figure 4](image4.png)  
**Figure 4.** Contour map of consumed time under 6 triggered stations in current stations network.

Figure 3 shows that the minimum consumed time for early warning is 8.17s under three triggered stations in Gansu, the minimum radius of the blind zone is 24.92km. The consumed time for early warning is shorter than 15s in central and southern Gansu and is longer than 30s in northern Jiuquan. It
is obvious that the consumed time for early warning in central eastern and southern Gansu is shorter than that in northwestern Gansu.

Figure 4 shows that the minimum consumed time for early warning is 10.13s under six triggered stations in Gansu, the minimum radius of the blind zone is 32.79km. Within 300km from Lanzhou, consumed time for early warning is shorter than 15s because of heavily-dense observation network. Consumed time for early warning is longer than 40s and the radius of the blind area is above 141.61km in northern and western Jiuquan. Obviously, consumed time for early warning under six triggered stations in Gansu is unevenly distributed.

4.2 Analysis on consumed time for early warning in future earthquake early warning stations network

Under the set conditions, the contour maps of consumed time for early warning under three triggered stations and six triggered stations of the future earthquake early warning stations network are shown in Figures 5 and 6.

![Figure 5](image1.png) ![Figure 6](image2.png)

Figure 5 shows that the minimum consumed time for early warning will be 7.51s under three triggered stations in Gansu, and the minimum radius of the blind zone will be 22.13km. In addition, the consumed time for early warning will be shorter than 15s in areas except for some parts of Jiuquan, and that in the central and eastern Gansu will be shorter than 10s.

Figure 6 shows that the minimum consumed time for early warning will be 7.64s under six triggered stations in Gansu, and the minimum radius of the blind zone will be 22.69km. In addition, the consumed time shorter than 10s in the central and southern Gansu areas accounts for 39.13% of the provincial area. Except for some parts of Jiuquan, the consumed time for early warning in other areas of Gansu will be shorter than 20s.

From the analysis, consumed time for early warning is closely related to the station density and distribution. Due to the high station density in central and eastern Gansu and the low station density in Jiuquan and Zhangye, consumed time for early warning in Gansu is unevenly distributed and presents obvious regional differences. Consumed time for early warning in central eastern and southern Gansu is obviously shorter than that in northwestern Gansu.

5. Comparative analysis on consumed time for early warning

5.1 Overall comparative analysis on consumed time for early warning

From the analysis on consumed time for early warning in Gansu, the average consumed time for early warning of the current earthquake early warning stations network under three triggered stations and six triggered stations is 19.62s and 26.59s respectively, and the average consumed time for early warning of the future earthquake early warning stations network under three triggered stations and six triggered stations is 14.24s and 17.43s respectively. The consumed time for early warning of the future
earthquake early warning stations network under three triggered stations and six triggered stations in Gansu is shortened by 29.24% and 37.13% compared with those of the current earthquake early warning stations network, and moreover, shortened by more than 50% in some areas.

5.2. Analysis on Probability of consumed time for early warning

Table 1 shows the proportion of data volume in individual time intervals when consumed time for early warning data is divided by time intervals. Figures 7 and 8 show the probability curves of consumed time for early warning in the current and the future earthquake early warning stations network under three triggered stations and six triggered stations.

| Category | Consumed time interval | 3 triggered stations | 6 triggered stations |
|----------|------------------------|----------------------|----------------------|
|          | Current stations network | Future stations network | Current stations network | Future stations network |
| Category I | [min, 10s] | 2.77% | 47.71% | 0% | 39.13% |
| Category II | (10s, 15s] | 31.13% | 16.10% | 13.13% | 16.49% |
| Category III | (15s, 20s] | 25.90% | 13.79% | 20.34% | 8.41% |
| Category IV | (20s, 30s] | 29.62% | 8.21% | 28.18% | 21.58% |
| Category V | (30s, 40s] | 9.25% | 3.34% | 28.48% | 11.82% |
| Category VI | (40s, max] | 1.33% | 0.85% | 9.87% | 2.57% |

From Table 1, 80% of consumed time data in the current earthquake early warning stations network is distributed between 10s-40s, while about 60% of consumed time data in the future earthquake early warning stations network is distributed within 15s. In addition, the proportion of consumed time longer than 40s is lower than 5%.

According to the data analysis of consumed time for early warning in the future and current earthquake early warning stations network under three triggered stations, consumed time for early warning in Category I and Category II in the future stations network increases by nearly 88.23% from those of the current stations network. Specifically, the data in Category I is increased by 16 times from that of the current stations network, while the data in Category V and Category VI is reduced by 60% from that of the current stations network.

From the data analysis of consumed time for early warning in the future and current earthquake early warning stations network under six triggered stations, the data of Category I and Category II is increased by 3.24 times from that of the current stations network, the data of Category I increases from 0% in the current stations network to 39.13% in the future stations network, and the data of Category V and Category VI is reduced by 74% from that of the current stations network.

Figure 7. Probability of consumed time for early warning under three triggered stations.
Figures 7 and 8 show that the probability of consumed time for early warning in current earthquake early warning stations network is relatively uniform, mainly distributed between 10s-40s. The probability of consumed time for early warning in future earthquake early warning stations network is relatively uneven, high on the start, low and stable in the middle and the end. The probability of consumed time for early warning of the future stations network shorter than 12s is higher and the probability of the consumed time longer than 35s is almost zero.

After the completion of the Gansu Subproject, the overall network density of Gansu earthquake early warning stations network will increase, and the distribution of the network will be more reasonable. Therefore, consumed time for early warning of the future earthquake early warning stations network will be significantly shorter than that of the current earthquake early warning stations network, which will increase the effective early warning time, reduce the radius of the early warning blind zone and greatly improve the early warning capability.

6. Conclusions
Gansu earthquake early warning stations network is a large and complex project, the analysis of consumed time for early warning, the effective early warning time and the radius of the early warning blind zone is conducive to understanding the early warning capability of the earthquake early warning stations network. Through the analysis and calculation of the previous chapters, we can draw the following conclusions:

(1) The effective early warning time is negatively correlated with consumed time for early warning, and the radius of the early warning blind zone is positively correlated with consumed time. Under shorting consumed time, the effective early warning time was increased, and the radius of the early warning blind zone was reduced. Consumed time for early warning directly reflects the early warning capability of the earthquake early warning stations network.

(2) The consumed time for early warning is closely related to the station density and distribution. Consumed time for early warning in Gansu is unevenly distributed and presents obvious regional differences, which in central eastern and southern Gansu is obviously shorter than that in northwestern Gansu.

(3) Under the set conditions in this paper, the consumed time for early warning of the future earthquake early warning stations network under three triggered stations and six triggered stations is shortened by 29.24% and 37.13% than those of the current earthquake early warning stations network, and even shortened by more than 50% in some areas. The probability of consumed time for early warning in the current earthquake early warning stations network is uniformly distributed between 10s-40s. However, the probability of the consumed time for early warning in the future earthquake early warning stations network is relatively uneven, high on the start, which mainly distributed between 7s-12s. After the completion of the Gansu Subproject, consumed time for early warning of the future earthquake early warning stations network will be significantly shorter than that of the current earthquake early warning stations network, which will increase the effective early warning time, reduce the radius of the early warning blind zone and greatly improve the early warning capability.
The work in this paper is fundamental. The analysis of consumed time for early warning of the current and the future earthquake early warning stations network assists us in better understanding the early warning capability of Gansu earthquake early warning stations network, which can provide reference suggestions for the future construction of the earthquake early warning system in Gansu.

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