ZONATION OF EARLY-WARNING CAPABILITY IN BEIJING CAPITAL CIRCLE REGION

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ABSTRACT:

The Beijing Capital Circle Region (38.5°-41.5°N, 113.5°-120°N) in North China is one of the critical regions with economic and cultural importance of seismic safety. Construction of an earthquake early warning system based on seismological networks is now underway. To optimize the network configuration for a better early warning function, as a process of planning and design, we map the early warning capability in this region based on the distribution of seismological stations, historical strong earthquakes, and seismic risk, for a 31×66 grid (with grid size 0.1º×0.1º). The distribution of seismic stations determines the warning reporting time; combining station distribution with distribution of historical earthquakes, early-warning time for the target to be protected can be calculated; areas where seismic hazard is relatively high while the EEW capability is relatively low are identified as the areas subject to the risk of destruction. This investigation can be used as a reference for urban planning, land use, and the deployment of key engineering and life-line systems, and most importantly, the upgrading of seismological networks for better early warning capability.

KEYWORDS: Capital Circle Region, Earthquake early warning system, Seismological networks

1. INTRODUCTION

Since the past few years, research and development of earthquake early warning (EEW) have shown significant potential for the mitigation of earthquake disasters (Heaton, 1985; Nakamura, 1988, 1989; Espinosa-Aranda et al., 1995; Kanamori et al., 1997; Wu and Teng, 2002; Allen and Kanamori, 2003; Kanamori, 2005; Wu and Kanamori, 2005a, b; Olson and Allen, 2005; Horiuchi et al., 2005; Wu et al., 2006; Wu and Zhao, 2006; Zollo et al., 2006; Boese et al., 2007; Wu and Kanamori, 2007; Wu et al., 2007; Wurman et al., 2007). Some counties/regions such as U.S., Japan, Mexico, and Chinese Taiwan have established practical EEW function, while other countries are testing EEW systems. EEW can provide a few seconds to tens of seconds of early-warning time for impending ground motions, which can be used for disaster mitigation measures.

Two types of EEW systems (front-detection EEW and on-site EEW) are currently in operation around the world and on-site system is more commonly used. In both cases time is a critical factor to consider. The signal processing speed of EEW systems decides whether effective warning information can be available before the strong ground motion arrives. EEW system in Capital Circle Region is based on the local digital seismological network. Unlike the economically developed areas such as Japan and California, the density of seismological network in Capital Circle Region is relatively low (111 stations in 15,0000 km^2). Moreover, seismographs are not well-distributed — the density is relatively high in the middle area and lower in the north and the south (Institute of Geophysics, CEA, 2006). To optimize the network configuration for a better early warning function, as a process of planning and design, the early warning capability in this region needs to be evaluated based on the distribution of seismological stations, historical strong earthquakes, and seismic risk. Mapping of the EEW capability is one of the products of such an evaluation. We consider such a mapping for a 31×66 grid, with grid size 0.1°×0.1°.

2. WARNING REPORTING TIME

Based on the description of Wu and Teng (2002), the warning reporting time T_r is determined by the time T_p needed for the system to be triggered by P-wave arrivals and the time T_e to process the waveforms for earthquake parameter estimation:

$$T_r = T_p + T_e \tag{2.1}$$

Obviously, effective early warning will not be available until this reporting time is less than the travel time of S-wave, i.e.,

$$T_w = T_s - T_r > 0 \tag{2.2}$$

Figure 1 give a sketch of the times defined in Equations (2.1) and (2.2).

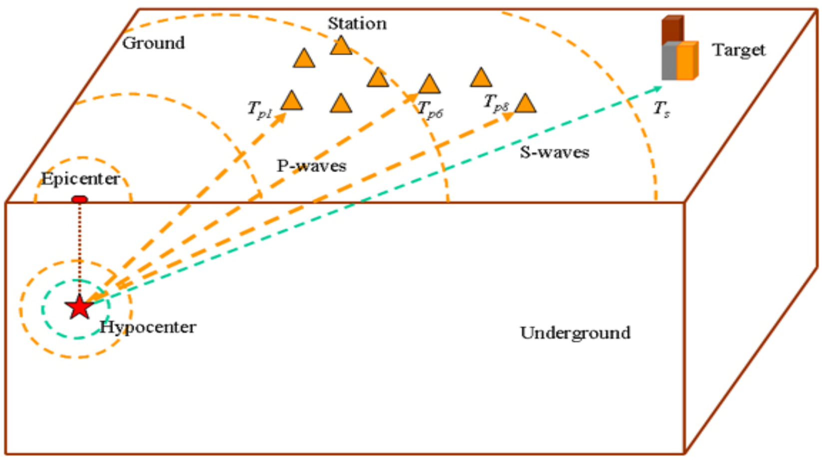

Figure 1 Sketch of EEW process. Triangles stand for seismographs, yellow arrow stands for P-wave and blue arrow stands for S-wave. T_{p1} is the time for P-wave reaching the nearest station. T_{p6} and T_{p8} are the time for P-wave reaching the 6th and 8th station, respectively. ‘Target’ shows the site to be protected by EEWS.

In EEW systems, multiple station records are usually used for earthquake parameter estimation. As shown in Figure 1, T_{p1}, the time for P-wave reaching the nearest station, is given by:

$$T_{p1} = \frac{\sqrt{D_1^2 + h^2}}{V_p} \tag{2.3.1}$$

where D_1 is the epicenter distance to the nearest station, h is the focal depth, and V_p is (the average/equivalent) P-wave velocity.

T_{p6} and T_{p8}, the time for P-wave reaching the 6th and the 8th station, respectively, are given by:

$$T_{p6} = \frac{\sqrt{D_6^{\ 2} + h^2}}{V_p} \tag{2.3.2}$$

$$T_{p8} = \frac{\sqrt{D_8^{\ 2} + h^2}}{V_p} \tag{2.3.3}$$

Previous study shows that the EEWS needs at least 3 seconds or more of P-waves to have a reasonable estimate of the lower limit of the earthquake magnitude (Erdik et al., 2003; Odaka et al., 2003; Olson and Allen, 2005; Rydelek and Pujol, 2004; Tsuboi et al., 2002; Wolfe, 2006; Wu et al., 1997). In this case, we take T_e=3s.

When the value of T_e is fixed, the warning reporting time T_r is determined by the density of seismological network around the epicenter. Suppose an earthquake occur at one grid point, with focal depth h=10km, and V_p=6km/s, we can estimate the warning time of this earthquake. By considering all the grid points, we can map the warning reporting time for each earthquake-supposed-to-occur. Figure 2a displays the distribution of seismic stations in the Beijing Capital Circle Region. Figure 2b maps the warning reporting time assuming that 6 stations are to be used for earthquake parameter estimation, and Figure 2c maps the warning reporting time assuming that 8 stations are to be used for earthquake parameter estimation.

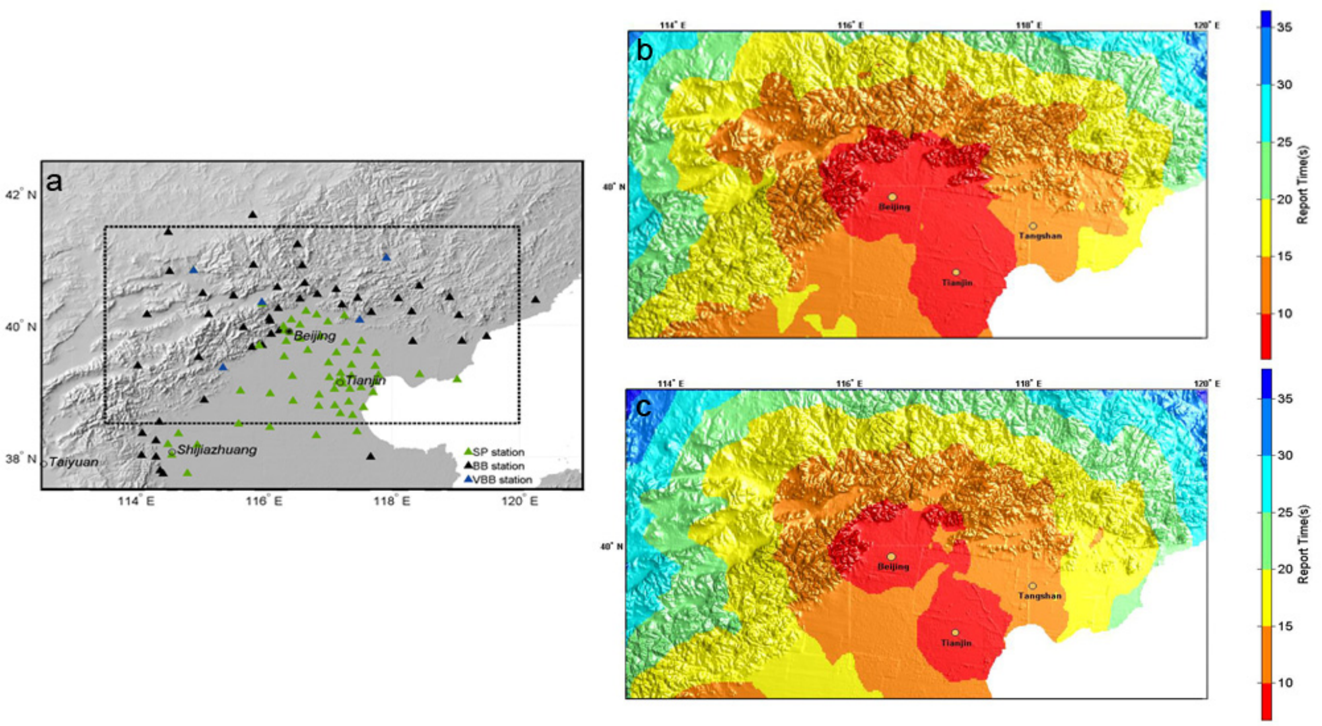

Figure 2 a) Distribution of seismic stations in Capital Circle Region. Boundary of the Capital Circle is shown in the figure by dashed lines. Green triangles stand for short-period seismographs, black triangles stand for broadband seismographs, and blue triangles stand for very broadband seismographs. b) Warning reporting time using the records of 6 stations. c) Warning reporting time using the records of 8 stations.

3. WARNING TIME AVAILABLE

As shown by (2.2), early-warning time

$$T_w = T_s - T_r \tag{3.1}$$

has to be larger than zero if an effective early warning is desired. T_s is related to the relative position between the earthquake and the target to be protected. At each site which is supposed to be the target to be protected, we consider all the earthquakes-supposed-to-occur with the same location as the historical earthquakes (as shown in Figure 3a). We consider the T_w value for all these potential earthquakes and take the minimum as the worst case. For each site this minimum value reflects the capability for the earthquake early warning system to protect the target at this site from the potential earthquakes located along the historical seismic belt. Figures 3b and 3c map the T_w for the case of 6 stations and 8 stations, respectively. If the value of T_w is less than zero, as shown by cold colors in the figures, then the site is exposed to the risk of destruction and cannot be protected by the present seismological system with EEW. In the perspective of disaster reduction, these blue areas can be regarded as the 'blind zones' of EEW.

The 130 historical earthquakes in the mapping is from the historical earthquake catalogues in north China ($M \geqq 5$ from 1500 to 1899, $M \geqq 4$ from 1900 to 2008). In the mapping we assume that the focal depths of these earthquakes are all 10km, and V_s=3.5km/s. It is understandable that the mapping of minimum early-warning time using the records of 8 stations for earthquake parameter estimation has larger 'blind zones'.

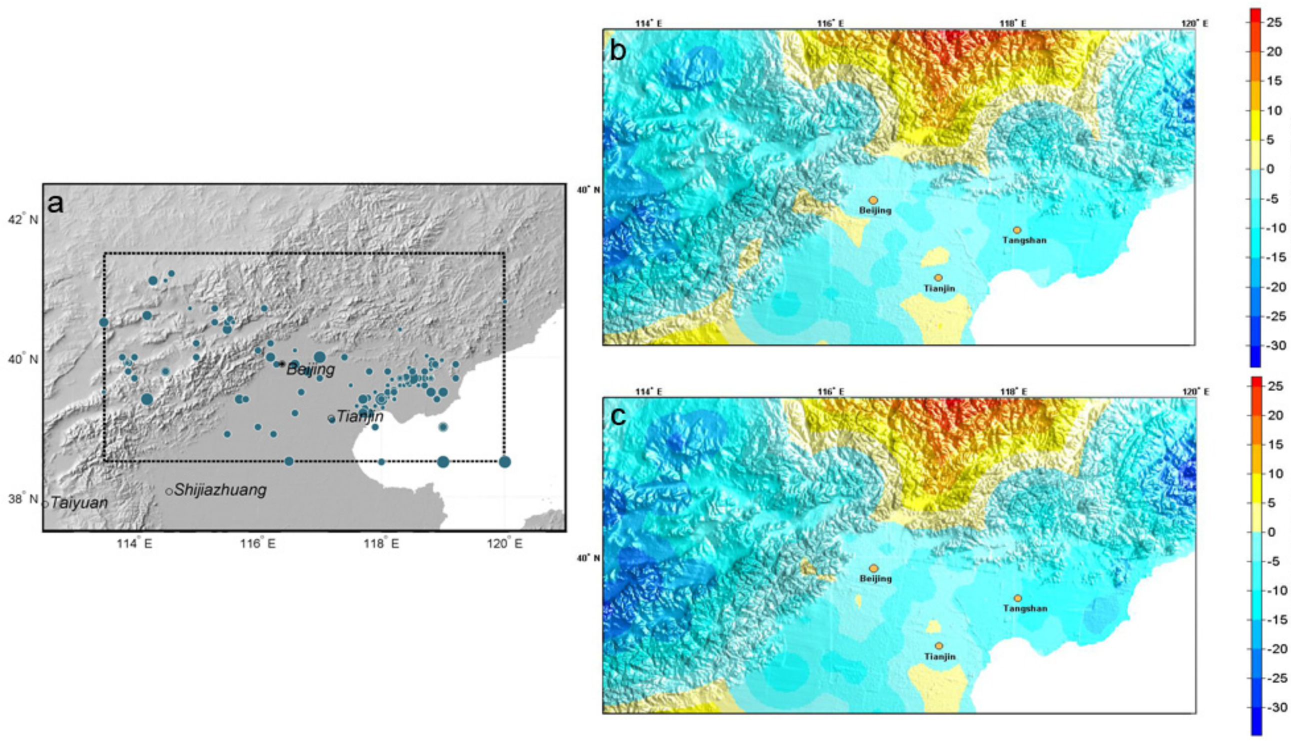

Figure 3 a) Distribution of historical earthquakes from 1500 to 2008 (blue circles) in the Capital Circle Region (delimitated by dashed lines). Note that earthquakes outside this region are not plotted in this figure. b) Minimum early-warning time for target at each grid point using the records of 6 stations for earthquake parameter estimation. c) Minimum early-warning time for target at each grid point using the records of 8 stations for earthquake parameters estimation.

4. AREAS EXPOSED TO RISK OF DESTRUCTION

Whether a ‘blind zone’ means that the site is really exposed to the risk of destruction is determined by the potential peak ground acceleration at this site. This parameter can be found from National Standard (2001) GB18306-2001 ‘Seismic Ground Motion Parameter Zonation Map of China’. The zonation map provides potential PGA with probability of exceedance 10% within 50 years. According to the peak ground acceleration zonation map, the potential PGA in the Capital Circle Region can be divided into four levels: 0.2g, 0.15g, 0.1g, and 0.05g, see Figure 4a.

We firstly pick out the areas where the minimum early-warning time is less than zero according to Figure 3b. The negative value of minimum early-warning time means that there is at least one earthquake in this area, being possible to cause damage to the target, with no warning information released before the strong ground shaking arrives. Whether the ground shaking will be ‘strong’ can be determined by the zonation map. Figure 4b shows the regions in the ‘blind zone’ with potential PGA no less than 0.2g. These areas include Huailai-Yanqing Basin, Beijing Region and Tangshan Region. From Figures 3b and 3c it can be seen that using 6 stations and 8 stations makes no difference for this mapping. Therefore only Figure 4b is used.

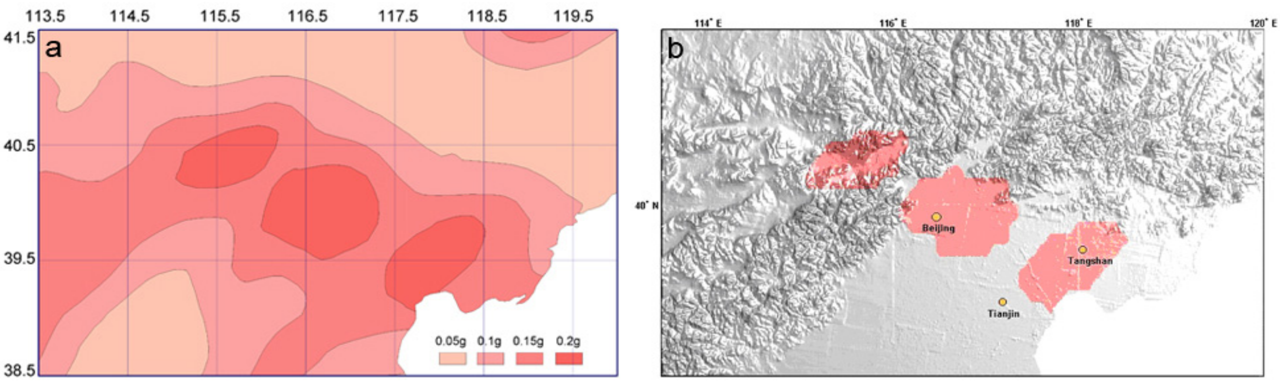

Figure 4 a) Seismic peak ground acceleration zonation map in Capital Circle Region. b) Area with high risk of destruction in Capital Circle Region in the perspective of EEW.

5. CONCLUDING REMARKS AND DISCUSSION

EEW system is playing an important role for earthquake hazard mitigation. The evaluation of warning capability is essential for system design. Two important parameters, warning reporting time T_r and early-warning time T_w, reflect the ‘ideal’ performance of an EEW system. T_r shows the time needed by the system to release the warning information, while T_w shows the response time provided by the EEW system before the destructive ground shaking arrives. Mapping the warning reporting time and minimum early-warning time in Capital Circle Region may provide information for the design and improvement of seismological observation systems for an early-warning purpose. The result shows that three areas, including Huailai-Yanqing Basin, Beijing Region and Tangshan Region, are exposed to seismic risk without effective protection by EEWS if the present seismological observation system is used for EEW. Improvement of this situation in the perspective of disaster reduction can be implemented by either deploying more seismic stations with real-time data transmission or enhancing the level of earthquake protection.

In our work, as a preliminary evaluation, simple half-space structure model is used. Considering the complexities of seismic wave propagation, the real picture of T_r will have some distortions. Historical earthquakes are used to indicate the location of potential earthquakes, showing the advantage of north China having long history of earthquake documentation and/or recording. At the mean time, considering the complexity of seismicity, such a simplification is sure to have limitations. In estimating the site-specific potential of ground motion, we directly used the national seismic zonation map. Despite all these limitations, the simple work presented in this report may be used as a reference for the design and planning of the EEWS.

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