30 Optimal Seismic Network Density for Earthquake Early Warning: A Case Study from California

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Introduction

One of the challenges with Earthquake Early Warning Systems (EEWS) is minimizing the “blind zone”—the region around an earthquake epicenter where no warning is possible because the strong shaking has already occurred by the time the alert is generated. There are factors that influence the radius of the blind zone area that are simply out of our control. For example, we cannot dictate exactly where and when earthquakes occur and how far individuals are from the earthquake epicenter. However, there are many things we can do to reduce the size of the blind zone. For example, improvements can be made to increase the warning time by some seconds by: a) using the most advanced telecommunication technologies that can potentially decrease the current telemetry delay; b) decreasing data packet size to less than 0.5 seconds; c) improving event detection and alert filtering algorithms; and d) well developed seismic networks with improved station density deployed across seismogenic zones. The degree to which these improvements can be made depends on how close the seismic stations are to the earthquake epicenter, as well as the distance between the warning site and the earthquake epicenter, the depth of earthquake, the density of the seismic network, the telemetry delay, and the time needed for decision making in regards to the type of warning that should be issued. For any practical use, the blind zones will be larger depending on the time required for a specific action.

We estimate how the average blind zone radius changes with varying interstation distances by examining inter-station distances from 1 km to 100 km (Figure 2.30.1). In our calculations, we first model typical California earthquakes, which, on average, have a relatively shallow depth of 8 km. We find that by increasing the station density 10 times (interstation distances from 100 to 31 km), the radius of the blind zone decreases by 57% from 73 km to 32 km. Increasing mesh density an additional 10 times (interstation distances from 31 to 10 km), the blind zone radius drops by another 37% from 32 km to 20 km. Increasing the station density by another factor of 10 (interstation distances from 10 to 3 km) reduces the radius by only 15% from 20 km to 17 km. We can also compute these estimates for the spatial extent of the blind zone area. A decrease of 57%, 37%, and 15% in blind zone radius corresponds to an 80%, 60%, and 28% drop respectively in total blind zone area.

We explored the distribution of interstation distances within the California Integrated Seismic Network (CISN). At each of the California stations we assign an average interstation distance value, which is computed from the average distance to the three closest stations. From these values we create a contour map of interstation distances using a linear interpolation between stations (Figure 2.30.2a).

We find that ~50% of California have an average interstation distance of 50 km or more (Figure 2.30.2a, primarily yellow regions), whereas highly populated areas, such as the San Francisco Bay and the Los Angeles regions have less than 30 km spacing (Figure 2.30.2a, green colors).

An EEWS should be devised to be the most robust at issuing alerts in regions identified as having high shaking potential from earthquakes, in combination with a large population base from the standpoint of probabilistic seismic hazard. For California, we assess which regions have both a high shaking potential (Figure 2.30.2b) and a large population density (Figure 2.30.2c). The seismic networks have been designed to have higher station densities in the regions of higher population. Qualitatively, regions that have both large populations as well as a high likelihood of experiencing strong shaking include: the extended Los Angeles and San Francisco Bay regions, and the southern part of the San Andreas Fault.

For the southern part of the Central San Andreas Fault (SAF), between San Jose and Los Angeles, we find there are an inadequate number of stations. In this critical part of California, the interstation distance varies from 30 to 50 km.

Based on quantitative estimates of the current CISN/EEWS infrastructure, we conclude that the blind zone radius throughout California is very heterogeneous. The minimum blind zone radius is ~16 km for typical California earthquakes with 8 km depth when a system requires at least four station detections...
and there is a four second processing/communications delay. Therefore, based on current constraints, there will be no time to issue a warning for any location within 16 km of a large earthquake. This limit of 16 km could be decreased if we address technical and algorithmic issues such as reducing the telemetry delay, decision-making time, etc.

The blind zone radius increases with larger interstation distance. Throughout most of the greater San Francisco Bay area and the Los Angeles area, blind zone radius is less than 30 km. These regions would likely get warnings for earthquakes that occur at distances greater than 20 km. In other regions of California, particularly in Northern California where the station spacing is much sparser (e.g., interstation distances of > 70 km), the blind zone radius is much larger. Our results show that successful warnings could only be issued for earthquakes at distances of 50 km from the earthquake location.

Three key factors which affect the optimization of interstation distance and station distribution are: I) budget, II) population/property distribution, and III) probability of expected earthquakes (past seismicity/known faults). In our budget-limited reality, however, optimum performance is also not achieved by even station distribution. Stations should be (1) densest (~10 km) in the urban areas that are above hazardous faults, (2) fairly dense (~20 km) along hazardous faults away from urban centers, and (3) least dense in other regions. Based on the current distribution of stations and hazards in California, the areas between San Jose and northern LA, and between Eureka and the San Francisco Bay Area need immediate attention if we would like to enhance EEWS in California.

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References


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