Frequency-Based Real-Time Magnitude Estimation for Earthquake Early Warning Systems

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Abstract:

Earthquake Early Warning System (EEWS) is a methodology for providing warning of forthcoming ground shaking during earthquakes. The approach uses a network of seismic instruments to detect the first-arriving energy at the surface, the P-waves, and translate the information contained in these low amplitude waves into a prediction of the magnitude and the peak ground shaking that follows. The instruments closest to the epicenter are the first to detect the seismic energy, and by using a seismic network this information can be integrated to produce a map of future ground shaking everywhere (Colombelli et al., 2015).

Keywords: Earthquake Early Warning Systems, predominant periods, τ_p, Iran.

1 INTRODUCTION

The frequency-based magnitude proxy employed in this paper is the predominant periods. This proxy, obtained using simple expressions that are valid for noise-free monochromatic signals, yield erroneous result. The τ_p, introduced in this study, is calculated directly from the actual velocity spectrum of the first few seconds of the seismic record. Using data from Central-Iran earthquakes whose magnitudes range between 4 and 6.5, it is demonstrated that τ_p is correlated with the catalog magnitude and provides better magnitude assessment than the characteristic period for small magnitudes. The average prediction error is reduced with increasing the input interval up to 5s. A new strategy for a P wave-based, on-site earthquake early warning system has been developed and tested on Iranian strong motion data. The key elements are the real-time, continuous measurement of three peak

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amplitude parameters and their empirical combination to predict the ensuing peak ground velocity. The observed parameters are compared to threshold values and converted into a single, dimensionless variable. A local alert level is issued as soon as the empirical combination exceeds a given threshold.

2 DATA

A composite data set is used that consists of Central-Iran earthquakes (Fig. 1) whose magnitudes range between 4-6.5. Only vertical components triggered seismograms are utilized. Figure (1) shows start time and selection of P-wave. The two data selection criteria that were used are that the signal to noise ratio (SNR) be greater than 5 and that the hypocentral distances be less than 50 km. These criteria guarantee that the data are of high quality and are (nearly) unaffected by anelastic attenuation. The sampling rate of the strong motion records is equal 200 sample per second.

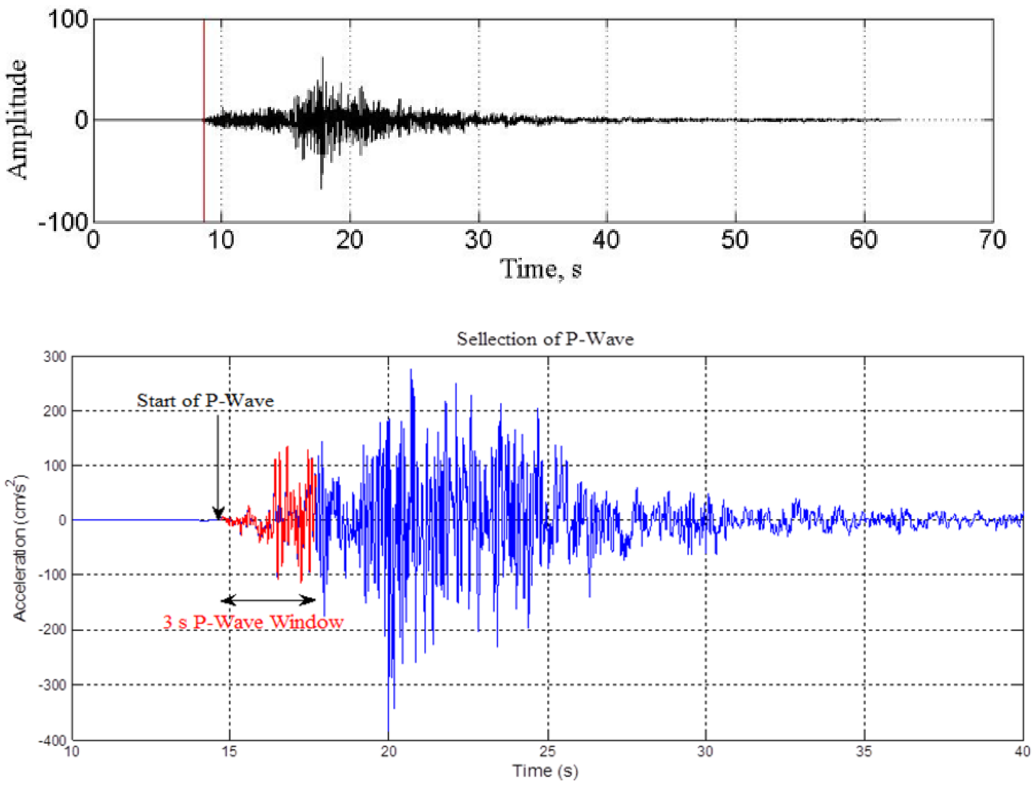
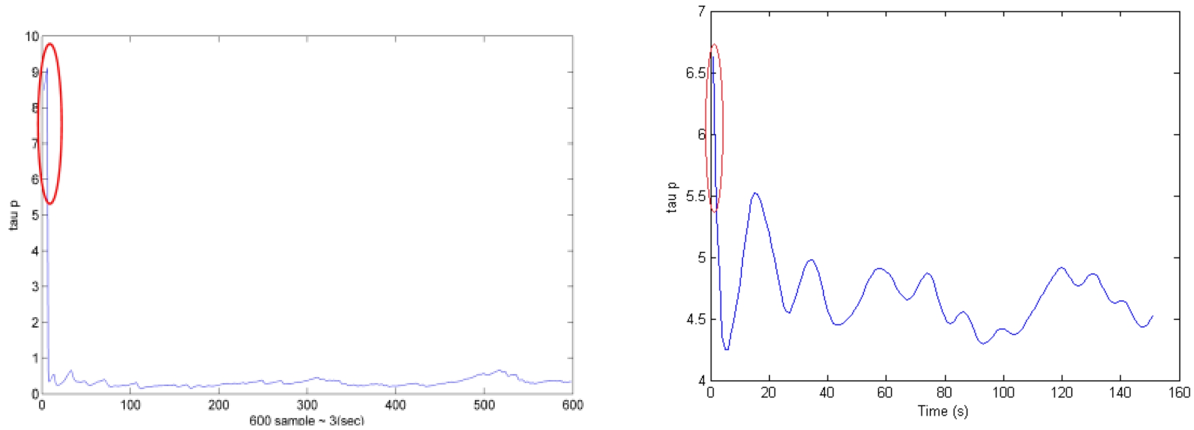


Figure 1: Record of the Qom Earthquake from Central-Iran



(a) (b)

Figure 2: The Estimated value of τ_p calculation for time series of a single record.

3 RESULTS

The performance of the method has been evaluated by applying the approach to the catalog of Iranian earthquake records and counting the relative percentage of successful, missed, and false alarms. We show that the joint use of three peak amplitude parameters improves the performance of the system as compared to the use of a single parameter, with a relative increase of successful alarms. The proposed methodology provides a more reliable prediction of the expected ground shaking and improves the robustness of a single-station, threshold-based earthquake early warning system. Allen and Kanamori (2003) introduced predominant period parameter (τ_p^{max}) based on the first 4 seconds of P-wave as well as records of earthquakes occurred in South California. Ziv (2014) defined log-average period (τ_{mlog}) method by using records of Japan and California earthquakes with magnitude between 3.5 and 7.3 and a hypocentral distance of less than 30 kilometers. He showed that $\tau\log$ is more correlated with the magnitude and shows more reliable results compared to τ_p^{max} and τ_c parameters. $\tau\log$ is determined based on frequency power spectrum of records of the initial part of velocity seismogram. In this study, The linear relations between τ_p and magnitude is used.

$$M = 0.68 * \log(\tau_p) + 5.2\text{ś}0.4 \tag{3.1}$$

1. Results from the Pacific Northwest and Japan show a scaling relation between earthquake magnitude and predominant period of the first few seconds of the P wave. The relations are similar to those previously observed in southern California (Allen and Kanamori , 2003; Allen et al., 2004; Lockman and Allen, 2005). The similarity of the scaling relations derived from datasets from different regions shows that the

magnitude-period relations are not sensitive to the variable attenuation characteristics of the different geologic environments or faulting style.

2. The sensitivity of magnitude-period relations can be optimized using different frequency bands of the waveform. Sensitivity to large-magnitude events (i.e., M 4.5) is maximized by low-pass filtering with a lower corner frequency than for small-magnitude events. Slightly different corner frequencies of the applied low-pass filters are found to be optimal for different regions.

3. The accuracy of the magnitude estimate increases as the number of stations providing predominant period observations increases.

4. The use of the P-wave arrival to assess the hazard posed by an earthquake maximizes the warning time available and could provide a warning in the epicentral region.

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