Soil Dynamics and Earthquake Engineering 92 (2017) 397–407

Contents lists available at ScienceDirect

Soil Dynamics and Earthquake Engineering

journal homepage: www.elsevier.com/locate/soildyn

Reliability assessment on earthquake early warning: A case study from Taiwan

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ARTICLE INFO

Keywords:
Earthquake early warning
False alarm
Missed alarm
Taiwan

ABSTRACT

Earthquake early warning (EEW) has been implemented in several regions around the world. However, because of natural randomness and uncertainty, false alarm and missed alarm can be expected in EEW. The key scope of this study is to evaluate the reliability of an on-site EEW in Taiwan, by testing the system's algorithm with 17,836 earthquake data from 1999 to 2013. The analysis shows that the on-site EEW system, empirically speaking, should have a false-alarm probability of 2.5%, and a missed-alarm probability of 14.1%. Considering missed alarm should be more critical to EEW, a new algorithm that could reduce the system's missed-alarm occurrences to 6% is also discussed in this paper.

1. Introduction

The region around Taiwan is known for high seismicity. As a result, a variety of earthquake studies were conducted for the region, including earthquake early warning [1–5]. Understandably, the working principle of earthquake early warning (EEW) is to send out warning messages to the public a few seconds before the arrival of peak ground shaking, utilizing the nature that radio waves can travel much faster than seismic waves [6]. Nowadays, EEW has been established in several regions around the world, including Taiwan, Japan, California, Mexico, Romania, and Turkey [7–16].

For example, Japan Railways first developed an alarm system along the tracks in the 1960 s to stop/deaccelerate moving trains immediately as long as the precursor threshold was exceeded by early earthquake motions [7]. By the current EEW characterizations, such a system is within the scope of on-site EEW, which relies on the precursor information detected at one site for EEW decision-making for the same site. On the other hand, the Japan Meteorological Agency (JMA) developed a different EEW approach by deploying a number of instrumentations along the east coast of Japan in an attempt to "dissect" occurring earthquakes in the offshore areas as early as possible (i.e., interpreting its magnitude and location). Then if the system judges a big earthquake is occurring, the information will be immediately sent out to high-speed trains with immediate deceleration in order to lower derailing likelihood as peak motions arrive [11]. But unlike the previous on-site system, the JMA system is referred to as a regional EEW by today's standard, utilizing ground motions that have been received by multiple stations closer to the earthquake to determine its magnitude and location as early as possible for EEW decision-making.

Like the JMA system, a similar EEW is now in operation in Mexico, by installing a number of instrumentations along the Guerrero Coast in an attempt to detect earthquakes in the offshore area as early as possible. Similarly, if a big earthquake is detected, early warning messages will be immediately sent out to the public of Mexico City for immediate responses and actions [13]. More recently, the CISN (California Integrated Seismic Network) EEW system in California is under testing, which is a new, hybrid system that integrates the essences of both on-site and regional systems into such a newly developed EEW approach [16].

Although earthquake early warning is considered a practical solution to earthquake hazard mitigation e.g., [13,17–21], its reliability is another research topic because not an EEW system can claim perfect accuracy without false/missed alarm. Therefore, in addition to methodology, the studies of EEW reliability have also been reported e.g., [22–27]. For example, Iervoline et al. (2009) [22] pointed out that ground motion prediction equations should play a more critical role than real-time estimations on earthquake magnitude and location, as far as regional EEW is concerned .

On the other hand, with the data from the PEER ground motion database (Pacific Earthquake Engineering Research Center), Wang et al. (2013) considered that using multiple precursors can predict

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http://dx.doi.org/10.1016/j.soildyn.2016.10.015
Received 19 December 2014; Received in revised form 22 February 2016; Accepted 16 October 2016

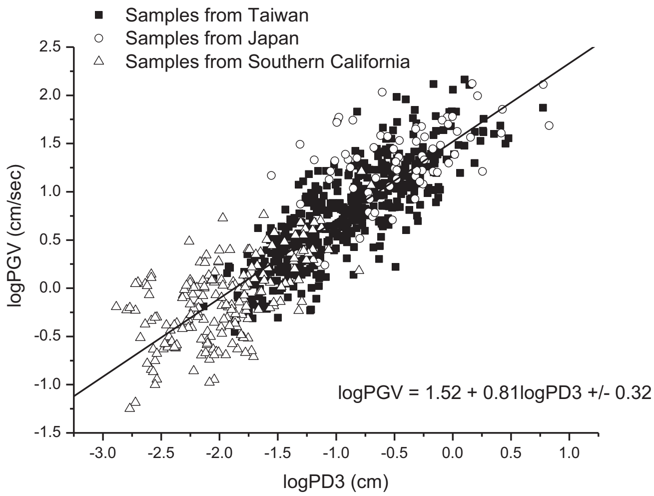

Fig. 1. A regression model between PGV and PD3 for on-site earthquake early warning (after Wu and Kanamori [29]).

earthquake peak motions more accurately, then increasing the reliability of an on-site system [23]. Note that such an approach and suggestion are similar to the study of Böse et al. (2009), pointing out that the false triggers can be substantially reduced by utilizing multiple precursors in the calculations [24]. Instead of focusing on improving the real-time estimation's accuracy, Wang et al. (2012) adopted a different approach in an attempt to improve the decision-making reliability of EEW from the perspective of risk reduction, which not only considers false-alarm and missed-alarm probabilities, but also the consequences of the two errors [25]. Other studies relevant to EEW reliability include the developments of the automated EEW decision-making for engineering purpose in particular [26], as well as the epistemic uncertainty issues, such as which empirical relationship should be used in the algorithm, that could also affect the reliability of EEW [27].

Different from those EEW reliability studies, the scope of this study is to evaluate the reliability of an on-site EEW system in Taiwan. In short, the methodology of the study is to test the system with historical data, then counting how many false alarms and missed alarms will be occurring among the 17,836 tests. The result shows that among the 17,836 tests, 437 false alarms and 2516 missed alarms would be occurring with the current algorithms, in corresponding to a false-alarm probability of 2.5%, and a missed-alarm probability of 14.1% from an empirical point of view.

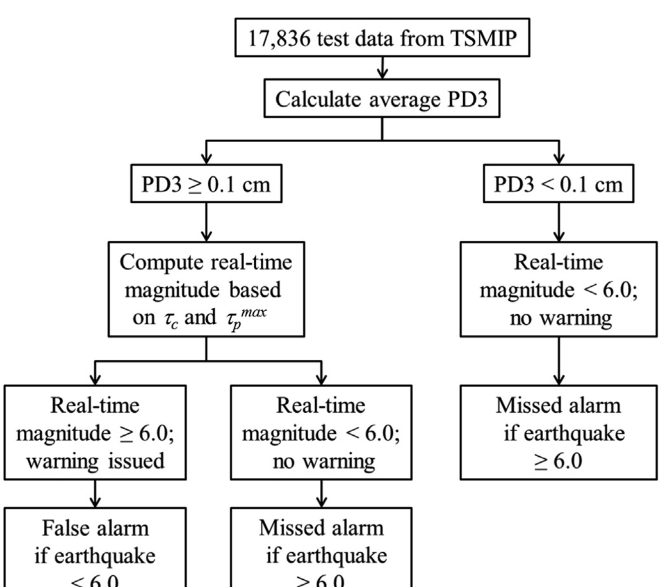

Fig. 2. The on-site EEW decision-making and the methodology of the reliability assessment.

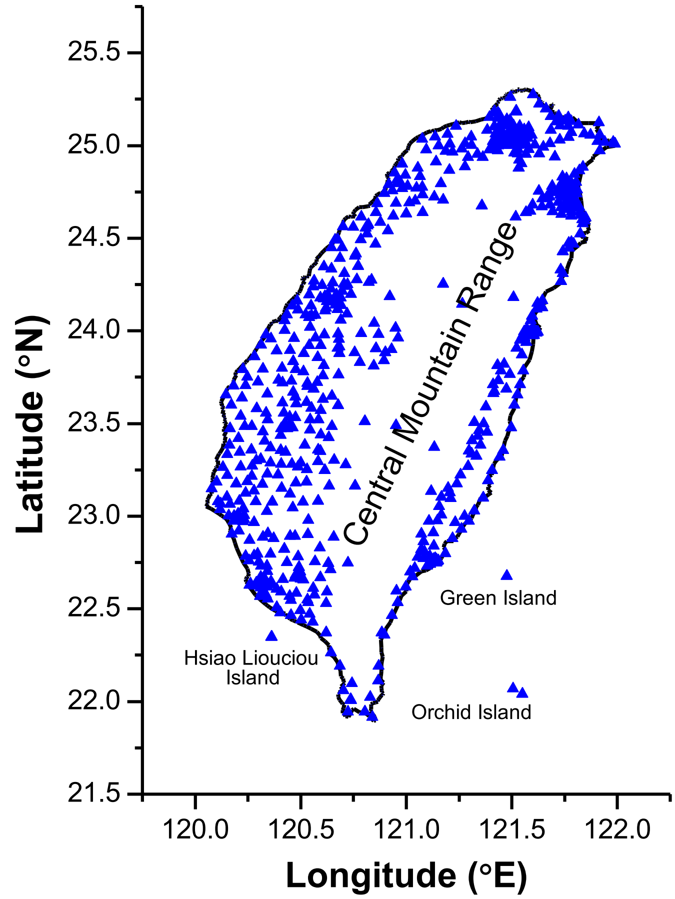

Fig. 3. Locations of 700 earthquake stations of the Taiwan Strong Motion Instrumentation Program (TSMIP).

2. The on-site EEW system in Taiwan

2.1. Overview of EEW methodology and algorithms

Earthquake early warning can be mainly categorized into two types: regional and on-site. Generally speaking, a regional EEW system is to utilize information from multiple stations close to the earthquake for estimating its magnitude and location (i.e., hypocenter/epicenter) as early as possible, then using the real-time information for EEW decision-making for farther sites utilizing the nature that radio waves (for data transmitting) can travel much faster than seismic waves. By contrast, an on-site system is based on the estimate of earthquake magnitude or peak motion at a target site, which is predicted based on the precursor or early motion that has been received/detected at the same site. Note that because such a system is mainly utilizing earthquake information from one site (also referred to as the target site), the

Table 1
Summary of the 17,836 data used for the EEW reliability assessment.

	$M_L < 6.0$	$M_L \geq 6.0$	Total
No. of earthquakes	253	41	294
No. of waveforms	14,150	3,686	17,836