On-Site Earthquake Early Warning System as an Alternative Earthquake Mitigation Solution in Indonesia

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Abstract

The Banten earthquake, which had a magnitude of 6.6 on January 14, 2022, damaged 3,078 houses. That number consisted of 395 heavily damaged units, 692 moderately damaged units and 1,991 lightly damaged units (Tempo.co, 2022). The Banten earthquake was a strong earthquake where the magnitude was greater than a scale of 5. Damage to houses caused by the earthquake occurred in most single-story houses or low-rise buildings. Given the large number of one-story houses that are damaged every time a major earthquake occurs in Indonesia, there needs to be appropriate mitigation measures to reduce the risk of earthquake disasters, especially for human casualties. An On-site Earthquake Early Warning System (On-site EEWS) can be an alternative in reducing victims of the disaster. This earthquake early warning system has sensors that are installed on the site of building houses and can predict strong earthquake waves that are destructive in nature (S/Secondary Waves) through P/Primary Waves that arrive early in about 10-20 seconds. This time is sufficient for evacuation for the occupants of a one-story house if the early warning alarm is properly responded to. This early warning radius can reach 20 km from the on-site EEWS location considering that this area has relatively the same vibration effect. Currently, Indonesia through the BMKG is developing EEWS as a part of the existing earthquake mitigation system. The purpose of this study is to describe the application of an on-site earthquake early warning system as an alternative solution for earthquake mitigation in Indonesia. This study evaluates several EEWS applications in the literature to find the best alternative to be applied in Indonesia. The critical factors for on-site implementation of the EEWS discussed in this paper are compared with the Taiwan regional EEWS. Based on the existing validation, the on-site EEWS has an 80% accuracy rate in predicting the intensity level of a strong earthquake, capable to automatically send an alarm message within 3 seconds and providing a warning time of at least 8 seconds before a destructive peak S wave arrives.

Keywords: earthquake early warning, earthquake disaster, on-site EEWS

1. Introduction

Earthquake mitigation is a series of efforts to reduce the risk of earthquake disasters. The major earthquake disaster mitigation scheme includes the Earthquake Preparedness Stage, the Emergency Response Stage, and the Post-Earthquake Restoration Stage. The Earthquake Preparedness Stage includes a program for developing and revising earthquake regulations, seismic and retrofit assessments, and isolation of critical facilities. These programs include proposing seismic provisions and revisions, seismic assessment and retrofit, isolation technology for critical facilities, ensuring life and property safety, and preparing disaster mitigation and rescue plans [1].

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The Emergency Response Phase includes the EEWS (Earthquake Early Warning System) program, initial seismic loss estimation, and monitoring the health of building structures. Activities in this program are early warning of strong earthquake attacks, early loss estimation, and monitoring of critical infrastructure, and emergency response actions. Whereas in the Post-Earthquake Restoration Stage, programs that can be carried out are Rapid Recovery Technology, Rapid Evaluation Technology, and Structural Collapse Simulation. Activities at this stage provide post-earthquake rescue facilities, rapid evaluation of structural damage status, and help restore buildings [1]. This study discusses the Earthquake Early Warning System as part of earthquake disaster mitigation in the Emergency Response Stage.

Indonesia does not currently have an effective earthquake early warning system (EEWS) to warn the public before the actual waves of damaging earthquakes occur. The information on the magnitude of the earthquake detected and published is the peak of the earthquake wave so there is no warning time for the community to evacuate before the destructive earthquake wave arrives.

The on-site earthquake early warning system (On-site EEWS) can be an alternative solution because it is able to detect the initial wave (P/primary wave) and provide an early warning alarm so that people living in one-floor houses or on the first floor of a building can evacuate before the peak destructive S/secondary/shear waves occur [2]. Evacuation of occupants of a one-story house is important because based on data on house damage due to the earthquake, most one-story houses or low-rise buildings occurred [3], [4]. As one example, the Banten earthquake which occurred on January 14, 2022, had a magnitude of 6.6 and caused as many as 3,078 houses to be damaged. This number consisted of 395 housing units which were heavily damaged, 692 units were moderately damaged, and 1,991 units were slightly damaged [4]. Considering that most one-story houses are damaged every time a strong earthquake (scale M> 5) occurs in Indonesia, there needs to be appropriate earthquake mitigation measures to reduce the risk of an earthquake disaster, especially for human casualties. This study aims to describe the implementation of an on-site earthquake early warning system as an alternative earthquake mitigation solution in Indonesia.

2. Material and Method

This study evaluates several EEWS applications in the literature specifically related to EEWS developed in Taiwan to get one of the best alternatives to be implemented in Indonesia. Important factors for the implementation of the on-site EEWS/on-site earthquake early warning system discussed in this paper are compared with the Taiwan regional EEWS.

The development of an on-site earthquake early warning system has been carried out in Taiwan [5] coordinated by NCREE (National Center for Research on Earthquake Engineering). The development of an on-site earthquake early warning system in addition to the existence of the Taiwan regional EEWS is very reasonable because this country is a country that has earthquake-prone conditions similar to earthquake conditions in Indonesia which are above active tectonic plates [6]. The combination of the on-site earthquake early warning system and regional EEWS in Taiwan has been verified as an effective tool for earthquake disaster prevention in elementary schools in Taiwan [7].

The on-site earthquake early warning system is able to predict the initial waves (P-waves) which will come faster than the destructive S waves because the velocity of the P waves is around 5~7 km/sec, while the more destructive S waves are around 3~4 km/sec. The on-site earthquake early warning system takes advantage of the difference in the velocity of the two waves as an opportunity for earthquake disaster mitigation in reducing human casualties. In a very minimal time calculation using previously detected P waves, it can predict the intensity of future strong earthquakes which are very damaging in nature [8]. In the on-site earthquake early warning system, to reduce or even eliminate false alarms due to non-earthquake vibrations caused by human or vehicle vibrations, the on-site EEWS is equipped with backup sensors. The on-site EEWS system, which is equipped with a backup sensor, can distinguish wave signals caused by earthquakes and non-earthquakes [9].

In its development, the performance of the on-site earthquake early warning system has been verified with several earthquake events in Taiwan. One of them was the Meinong earthquake on February 5, 2016. During the Meinong earthquake there were no false alarms or missed alarms issued by the on-site earthquake early warning system [10]. The performance of the on-site earthquake early warning system was also proven during the Hualien Taiwan earthquake which occurred on February 6, 2018, especially for areas close to the epicenter where damage is more likely to occur, the system can provide early warning through an alarm before the occurrence of a damaging earthquake wave so that fatalities due to earthquakes can be significantly reduced [11]. To sound an early warning of the intensity of an impending earthquake, the on-site earthquake early warning system uses an artificial neural network (ANN) model to predict peak ground acceleration (PGA) from ground motion records based on P-wave parameters [12].

In this study, the application of the on-site earthquake early warning system used is based on the on-site EEWS developed by NCREE Taiwan. The on-site earthquake early warning system is an earthquake early warning system whose sensors are installed in the ground at the building site. In brief, the working principle of the on-site earthquake early warning system is as follows. Sensors installed on the ground capture the initial earthquake waves (P-waves), then proceed to the calculation system to produce predictions of earthquake intensity. If a certain intensity is generated that is dangerous, the system will automatically trigger an alarm so that people can evacuate before the more destructive S wave arrives. This system is also equipped with backup sensors to distinguish between the initial seismic waves and non-seismic waves caused by vibrations caused by humans and passing vehicles. The on-site earthquake early warning system equipment consists of routers, DAQ data acquisition systems, IPC, UPS, initial wave receiving sensors, and backup sensors (Fig. 1). The on-site earthquake early warning system provides a local prediction tool for coverage of areas with the same vibration range within a 20 km radius from the location of the on-site EEWS tool (Fig. 2).

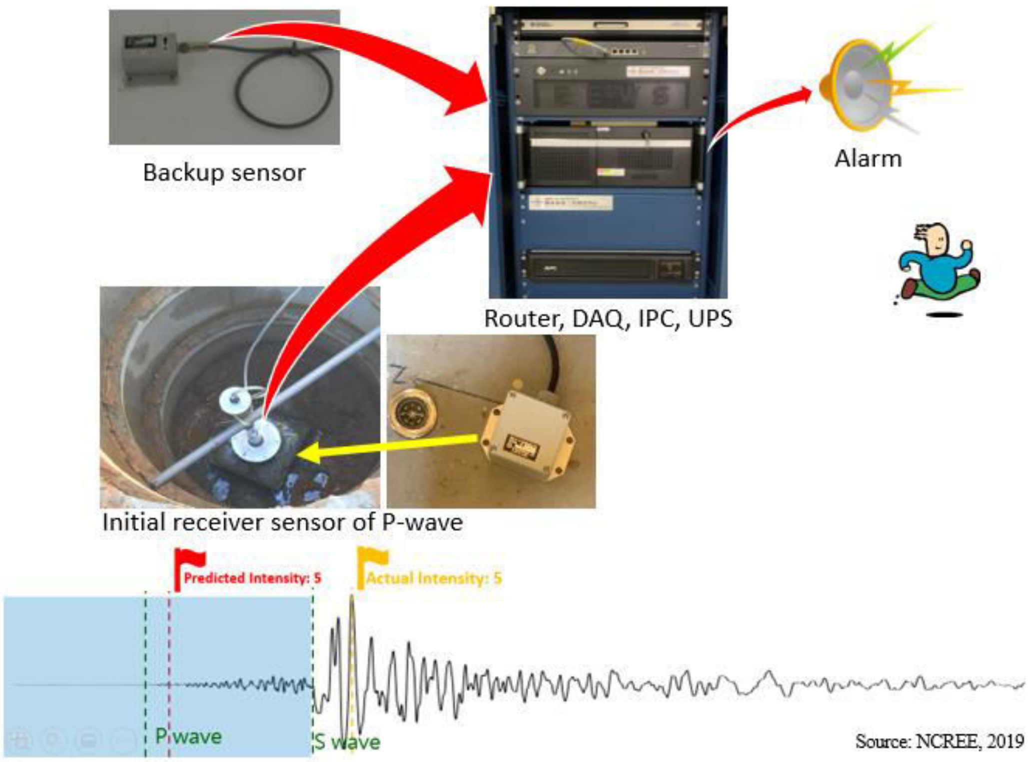

Fig. 1 On-site earthquake early warning system

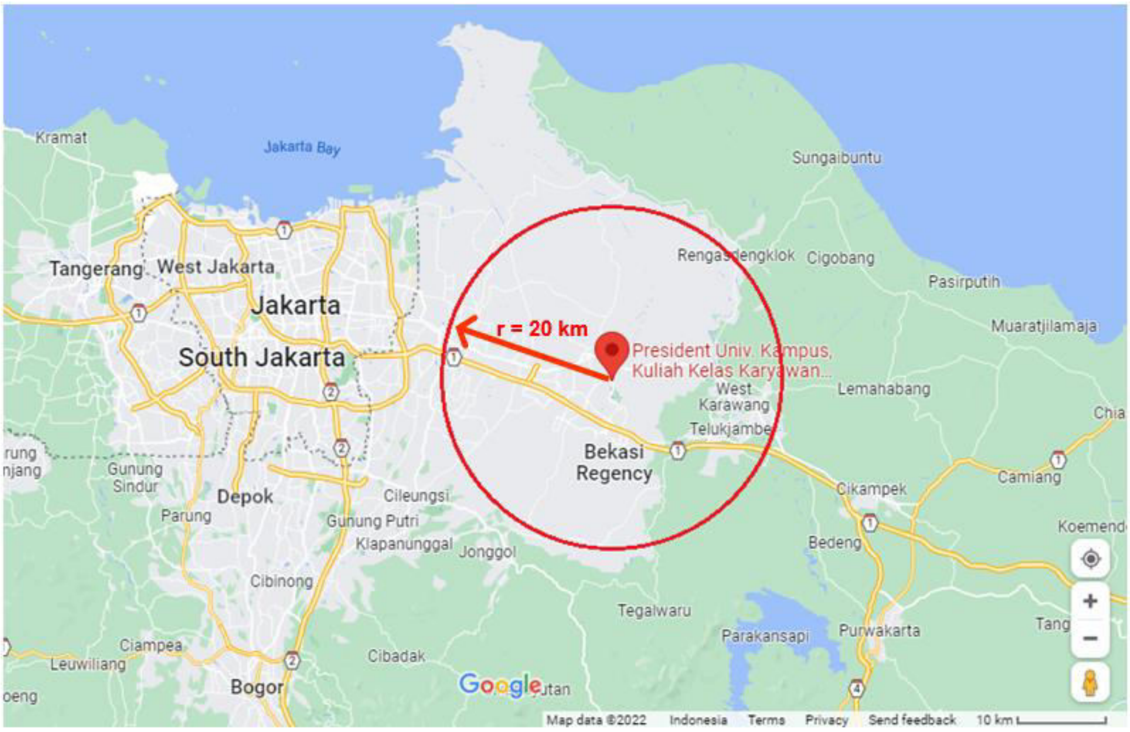

Fig. 2 The coverage area of the on-site earthquake early warning system

Due to the similarity of the coverage of the vibration area within a 20 km radius of the on-site EEWS tool, an earthquake early warning alarm can be broadcast to residents in the coverage area for evacuation if a damaging earthquake intensity is predicted. The evacuation referred to here is for residents of houses or buildings on the first floor considering the short early warning time before the peak of the S wave occurs. Meanwhile, occupants of houses or buildings on the second floor and above can protect themselves according to existing earthquake mitigation standards.

Important factors in implementing an on-site earthquake early warning system are the level of accuracy in predicting earthquake intensity and early warning time based on the initial capture of the primary earthquake wave (P-wave) [13]. To investigate the effectiveness of this on-site earthquake early warning system, important factors in the application of the system such as the accuracy of the prediction of earthquake intensity, the time when the early warning was broadcast, and the early warning time before the peak of the S wave, will be compared with the Taiwan regional EEWS which will be discussed in the following section.

3. Results and Discussion

A comparison of the important factors in the application of the on-site earthquake early warning system (accuracy in predicting the intensity of an earthquake, when the early warning is broadcast, and when the early warning before the peak of the S wave) with the Taiwan regional EEWS can be seen in Table 1.

Table 1 Comparison of important factors in the application of earthquake early warning systems

Factor	EEWS	
	on-site	regional
The level of accuracy of the prediction of earthquake intensity	80%	secure
Alert time is broadcast	3 seconds	18~20 seconds
Warning time before peak S-wave	minimum 8 seconds	no minimum time

Table 1 indicates that the level of accuracy of the prediction of earthquake intensity by the on-site EEWS is 80%, alert time is broadcast in 3 seconds, and warning time before peak S-wave is minimum 8 seconds [5]. Meanwhile the regional EEWS provides a secure level of accuracy of the prediction of earthquake intensity, alert time is broadcast in 18~20 seconds, and no minimum warning time before peak S-wave [7]. Based on comparative data on important factors for earthquake early warning system applications in Table 1, the on-site earthquake early warning system provides faster prediction results with a warning time of 3 seconds being issued/broadcast, while the warning time before the peak S wave is at least 8 seconds. This is possible because only the data collected by the on-site seismic sensors are used in the calculation system so that the data processing time is significantly reduced, and earthquake alarms can be published earlier in the affected areas.

For example, in the case of the Taiwan Chi-chi earthquake on September 21,1999 which had an epicenter distance to Taipei County city of about 150 km, the on-site earthquake early warning system could issue an earthquake strike warning 34.02 seconds before the peak of the S wave arrived in the Taipei County area. Compared to the regional EEWS, the on-site earthquake early warning system provides an additional 27.3 seconds of response time [6].

For locations close to the epicenter such as 70 km from the epicenter, the on-site earthquake early warning system can provide a warning time of 10~20 seconds before the peak earthquake wave arrives. A warning time of 10~20 seconds is considered reasonable or sufficient for the evacuation of occupants on the first floor of a house or building. This warning time can be distributed to coverage areas with a radius of 20 km from the location of the on-site earthquake early warning system considering that this area has relatively the same vibration effect [5].

4. Conclusions

This study has described the application of an effective on-site earthquake early warning system in earthquake mitigation which is supported by important factors in its application such as the level of accuracy in predicting earthquake intensity, the time the warning is issued, and the early warning time before the peak of the S wave. on-site earthquake early warning in predicting the level of earthquake intensity accurately is 80% based on validation tests, and the warning time is broadcast within 3 seconds. Meanwhile, the earthquake early warning time is at least 8 seconds before the peak of the damaging S wave arrives. Early warning alarm messages can be broadcast to a coverage area that has a relatively similar vibration effect with a radius of 20 km from the position of the on-site earthquake early warning system device with the aim that people in the area can leave their homes to save themselves before the peak of the damaging S earthquake wave arrives.

For the development of an on-site earthquake early warning system in the future, with an increasing number of on-site EEWS nodes, they can then be connected to each other to form a national EEWS network.

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