PERFORMANCE ESTIMATION OF EARTHQUAKE EARLY WARNING SYSTEM FOR DISASTER REDUCTION IN WESTERN JAVA, INDONESIA

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Abstract

We estimated the performance of future earthquake early warning (EEW) system in Indonesia. We modeled casualty ratio over natural warning lead time (S-P time). We estimated the lead time by a proposed EEW system. We applied the casualty ratio model to estimate the casualty with and without EEW system.

We estimated the lead time by a proposed EEW system and applied the casualty ratio model to estimate the casualty with and without EEW system. We obtained the reduction of the casualty by the EEW system in the area with about 34 % and 3% for a scenario of an M8 subduction zone earthquake and for that of an M7 inland earthquake, respectively. We concluded that the increased lead time by the EEW can play an important role to reduce the number of casualty by future damaging earthquakes in western Java.

Keywords: Earthquake Early Warning, Performance Estimation, Disaster Risk Reduction, Western Java.

1. INTRODUCTION

Although Indonesia has started a Tsunami Early Warning System in 2006 after the giant earthquake and tsunami in Sumatra on December 26, 2004, there were many large and devastating earthquakes occurred in Indonesia which caused thousands of people's deaths and injuries mainly due to collapses of non-engineered building and houses in Indonesia. Because of this, Indonesia government has a plan to establish an Earthquake Early Warning (EEW) system in Indonesia. The purpose of the study is to estimate the performance of a future earthquake early warning system in western Java, and has focuses on the estimation the reduction of casualty by implementing the EEW system in western Java in the future.

2. DATA

In this study, we used several dataset. The numbers of casualty and building damages from the past earthquakes in Yogyakarta, Tasikmalaya and Padang are used to model the casualty ratio due to heavily damaged houses in the past earthquake. We used 20 seismometer locations (Fig. 1) of the proposed EEW system by BMKG to estimate the warning performance, and two past earthquake epicenter locations (Table 1) for the scenario earthquakes. The demography data of western Java region in 2010 (BPS, 2010) is also used to estimate the number of URM (unreinforced masonry) houses and number of collapsed houses by ground shaking estimation from the earthquake and strong motion scenario. Estimated number of collapsed houses is used to estimate a casualty ratio and the number of casualty due to the earthquake and strong motion scenario and EEW performance for risk reduction

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Figure 1. Candidate of future EEWS seismic station in western Java. (BMKG, 2012). Two red stars are the epicenter of two earthquake scenarios.

Table 1. Scenario earthquake parameters.

Earthquake Scenario	Lat (S)	Lon (E)	Depth (km)	Mw
Scenario I (Subduction zone earthquake)	7.40	104.69	10	8.0
Scenario II (Inland earthquake)	6.86	106.94	15	7.0

3. THEORY AND METHODOLOGY

3.1 EEW System Performance Estimation

We introduced a new method to estimate the performance of future EEW system for seismic risk reduction. We assumed two earthquake scenarios with M8 for subduction zone and M7 for inland earthquake to estimate the strong ground motion acceleration (PGA) by using attenuation relationship formula by Si and Midorikawa (1999) and the arrival time of P and S wave at the capital city of every region and cities in western Java.

The estimated PGA and a fragility curve for URM houses proposed by Khalfan (2013) are used to estimate the number of collapsed or heavily damaged of the URM houses. The number of URM houses in every region and city in western Java is estimated from the published ratio of URM houses in rural and urban area we adopt 0.85 for rural area (Surahman, 2000) and assumed 0.4 for urban area, number population in every region. We also assumed occupancy density in every house to be 4.

We used data of casualty and damage loss of building houses from past earthquakes in Yogyakarta, Tasikmalaya and Padang to make a model of casualty ratio over S-P wave arrival time at the pointed capital city area from the epicenter of each earthquake event.

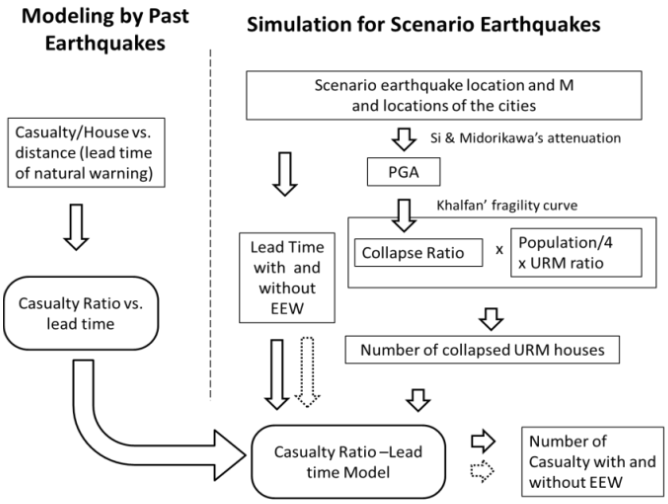

Figure 2. Flowchart of the study to estimate the number of casualty with or without EEW.

3.2. Casualty Ratio Modeling

A casualty ratio is defined as the number of casualties in one collapsed or heavily damaged URM house. We conducted a modeling by using earthquake loss data from the Yogyakarta earthquake on May 26, 2006, Tasikmalaya earthquake on September 2, 2009 and Padang earthquake on September 30, 2009 which is recorded by the National Disaster Management Agency of Indonesia (BNPB) to obtain the model. We estimated the casualty ratio in every region and city affected by each earthquake by Eq. (1).

We pointed the capital city of affected region to estimate the hypocentral distance, and we estimated the P-wave and S-wave arrival time to estimate the lead time by natural warning in every region.

$$casualty\ ratio\ (CR) = \frac{number\ of\ casualty\ (NC)}{number\ of\ collapse\ URM\ houses(CH)} \qquad (1)$$

We plotted the casualty ratio over the lead time and fitted into an exponential distribution, then we use it as the model to estimate casualty ratio in every region in western Java. Eq. (3) defined the casualty ratio as an exponential function of lead time. It means when people can have adequate lead time to evacuate before the strong ground shaking reached the area, the casualty ratio can be reduced

3.3 EEW -Lead Time Estimation

The lead time in EEW system is defined as the time difference between the S-wave arrival time at a certain area and the time of initial warning.

$$\Delta t = t_{sr} - t_{ps} - t_{proc} - t_{ds} \qquad (2)$$

where, Δt is a lead time or initial warning issuance, t_{sr} is the arrival time of S-wave at the region of target area (s), t_{ps} is the arrival time of P-wave at the closest distance of seismic station from the epicenter, t_{proc} is time for the system to estimate the earthquake parameter (hypocentral distance, magnitude and intensity) that is estimated as 3 seconds by using the first 3 seconds of the P-wave arrival at the closest station from the epicenter (Nakamura, 1988; Kanamori, 2005; Wu and Kanamori, 2005a; Wu et al, 2007; Wu and Kanamori, 2005b; Zollo et al., 2006; Wu and Kanamori, 2008a), and t_{ds} is the time that is used for warning dissemination processing and it's assumed as 5 seconds (Yamasaki, 2011). The 5 seconds assumption is based on 5.4 seconds of JMA's earthquake early warning issuance to the advance user and 8.6 seconds for general public issuance for Tohoku earthquake in 2011 (Hoshiba, et al., 2011; Yamasaki, 2011).

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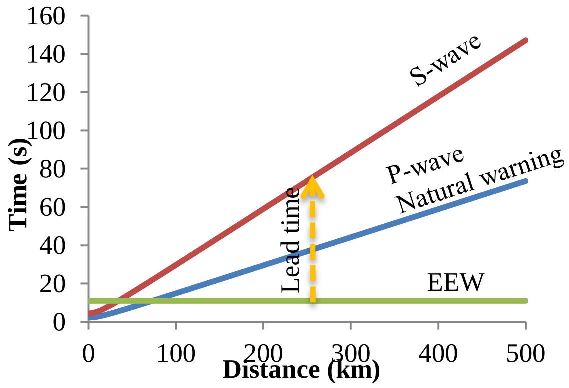

Figure 3. Lead time of the EEW system.

4.RESULT AND DISCUSSION

4.1. Results

By following the methodology, we obtained the reduction of the casualty ratio by the EEW system in the area in average about 34% and 3% for a scenario of an M8 subduction zone earthquake and for that of an M7 inland earthquake, respectively. The result is obtained as follow:

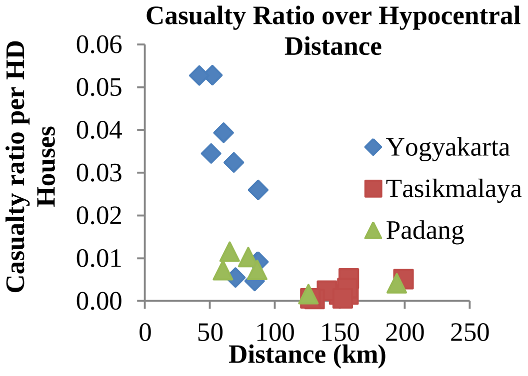

Figure 4(a).

4.1.1. *Model for Casualty Ratio*

We obtained the casualty ratio over distance for the past earthquakes (Fig. 4(a)). We modeled the casualty ratio as a function of the lead time of natural warning (Fig. 4(b)) by assuming homogeneous P-wave and S-waves velocities as 6.8 km/s and 3.4 km/s respectively (Gunawan, 2010). We neglected the earthquake rupture process to simplify the wave arrival time estimation at every region. We obtained

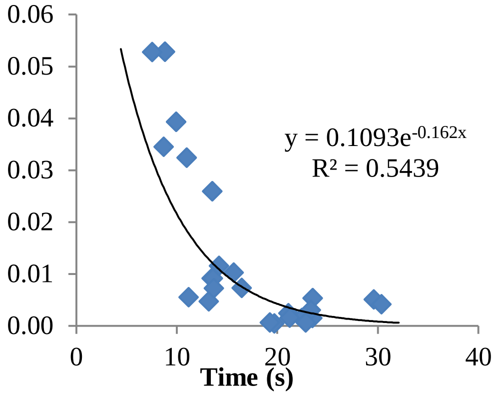

Figure 4(b).

Figure 4. (a) Casualty ratio from past earthquakes over hypocentral distance. (b) Casualty ratio over lead time as the model to estimate casualty ratio in every region of western Java.

the casualty ratio over lead time by fitting the model into an exponential distribution function (Fig. 4(b)).

$$CR = 0.1093\, e^{-0.162(t_{S-P})} \qquad (3)$$

where t_{S-P} is P-wave and S-wave arrival time difference or a lead time with or without EEW at every region.

4.1.2. *Damaged URM Houses due to Estimated Strong Ground Motion*

Si and Midorikawa (1999) attenuation formula is used into the scenario earthquakes to obtain the strong ground motion distribution in western Java. We estimated the number of collapsed URM building or heavily damaged houses due to estimated strong ground motion acceleration in every region by using fragility curve for URM houses in Bantul, Yogyakarta (Khalfan, 2013).

Table 2(a). Estimated Number of Casualty by an M8 Subduction Zone Earthquake Scenario Estimated number.

Regency/City	**Without EEW**	**With EEW**	**(%)**	**Regency/City**	**Without EEW**	**With EEW**	**(%)**
Kepulauan Seribu	1	0	100	Karawang	11	3	72.7
Jakarta Selatan	99	39	60.6	Bekasi	30	8	73.3
Jakarta Timur	82	27	67.1	Bandung Barat	8	2	75
Jakarta Pusat	33	11	66.7	Kota Bogor	87	51	41.4
Jakarta Barat	106	40	62.3	Kota Sukabumi	25	12	52.0
Jakarta Utara	44	14	68.2	Kota Bandung	4	1	75
Bogor	408	180	55.9	Cirebon	1	0	100
Sukabumi	268	117	56.3	Kota Bekasi	13	13	0
Cianjur	113	35	69	Kota Depok	96	40	58.3
Bandung	16	4	75.0	Cimahi	2	0	100
Garut	1	0	100	Tasikmalaya	1	0	100
Tasikmalaya	1	0	100	Banjar	1	0	100
Ciamis	1	0	100	Pandeglang	1,571	1160	26.2
Kuningan	1	0	100	Lebak	1,741	1264	27.4
Cirebon	1	0	100	Tangerang	572	384	32.9
Majalengka	1	0	100	Serang	126	97	23.0
Sumedang	1	0	100	Tangerang	138	66	52.2
Indramayu	1	0	100	Cilegon	148	143	3.4
Subang	1	0	100	Serang	268	258	3.7
Purwakarta	4	1	75	Tangerang Selatan	119	42	64.7
Total	**Without EEW 6,145**	**With EEW 4,012**	**(%) 34.7**				

4.1.3. *Estimated Casualty Performance*

Table 2 (a) and 2(b) show the number of casualty in every region in western Java by using Eq. (3). Then we simulated the number of casualty in every region by adjusting the lead time. When the lead time of EEW system has 3 seconds longer, number of casualty can be reduced about 41% and when the lead time is decreased for 3 seconds, the number of casualty can be reduced about 18%. And for an M7 inland earthquake scenario, when the lead time of EEW system is increased 3 seconds longer, the number of casualty reduction is increased, become almost 14%. And when the lead time of EEW system has 3 seconds decreased, the number of casualty reduction is become less than 2 % (Table 3).

Table 2(b). Estimated Number of Casualty by an M7 Inland Earthquake Scenario.

Regency/City	**Without EEW**	**With EEW**	**(%)**	**Regency/City**	**Without EEW**	**With EEW**	**(%)**
Kepulauan Seribu	10	3	70	Karawang	5,528	5,528	0
Jakarta Selatan	5,516	5,516	0	Bekasi	6,765	6,765	0
Jakarta Timur	6,991	6,991	0	Bandung Barat	5,487	5,487	0
Jakarta Pusat	1,926	1,926	0	Kota Bogor	6,896	6,896	0
Jakarta Barat	4,423	4,423	0	Kota Sukabumi	2,869	2,869	0
Jakarta Utara	3,155	3,155	0	Kota Bandung	5,265	5,265	0
Bogor	27,683	27,683	0	Cirebon	22	2	90.9
Sukabumi	28,726	28,726	0	Kota Bekasi	5,808	5,808	0
Cianjur	22,094	22,094	0	Kota Depok	7,302	7,302	0
Bandung	9,224	9,224	0	Cimahi	1,493	1,493	0
Garut	1,878	814	56.6	Tasikmalaya	139	28	79.9
Tasikmalaya	641	160	74.9	Banjar	12	1	91.7
Ciamis	256	36	85.8	Pandeglang	1,166	590	49.4
Kuningan	131	16	87.8	Lebak	2,870	2,748	4.3
Cirebon	235	29	87.7	Tangerang	5,178	4,828	6.8
Majalengka	395	95	75.9	Serang	343	158	53.9
Sumedang	1,155	624	45.9	Tangerang	3,159	3,029	4.1
Indramayu	273	40	85.5	Cilegon	128	35	72.7
Subang	2,312	1,655	28.4	Serang	371	151	59.3
Purwakarta	2,746	2,746	0	Tangerang Selatan	3,381	3,381	0
Total	**Without EEW**	**With EEW**	**(%)**				
	183,952	**178,320**	**3.1**				

Table 3. Estimated casualty reduction by adjusting lead time of EEW system with 3 seconds longer or 3 seconds faster.

Estimated Number of casualty				Estimated Casualty Reduction with EEW system and its adjustments (%)		
without EEW	with EEW	EEW system lead time adjustment				
		+3s	-3s	0s	+3s	-3s
M8 Subduction Earthquake Scenario						
6,145	4,012	3,640	5,044	34.7	40.8	17.9
M7 Inland Earthquake Scenario						
183,952	178,320	158,492	181,321	3.1	13.8	1.4

4.2. Discussions

We obtained the result by assuming that the scenario earthquakes occurred in the evening or in the morning time when people are awake in URM houses. We also assumed that people have the same response between the natural warnings and an EEW system. These assumptions was introduced to simplify the human behavior before and during the earthquake, because until now, there is no such data to estimate casualty caused by heavily damaged URM houses due to strong ground motion in Indonesia.

The EEW system performance depends on the initial time of warning issuance, and physical and psychological condition for human response during the earthquake.

Time of occurrence and distance from epicenter also might affect the performance of EEW system. The short distance from epicenter will give strong shaking where people cannot stand on their foot, and they have inadequate time to have response on evacuation. An earthquake can occur in daylight, evening, midnight, early in the morning and in any physical condition we have at the time like we are working, studying, sleeping, playing, we are in the house, in a building or in a yard and etc. which can affect evacuation performance during the earthquake. These possibility conditions have taken account on the evacuation performance.

5. CONCLUSIONS

We concluded that the lead time has an important role to reduce the number of casualty for any location of the earthquake (Fig. 3, Fig. 4(b), Table 3 and Table 4). This is because we considered human response on saving their live with the lead time they have at the time when the earthquake occurred in the morning or evening when the people are awake in URM houses.

The EEW system can give a longer lead time if some component of the earthquake parameters determination processing and dissemination time can be reduced. Closest distance of the seismic station to the potential seismic source also has an important role to gain a longer lead time of the system, but for decreasing earthquake parameters determination processing time will be very difficult, because it might effect to the accuracy of the earthquake parameters. Another way to gain a longer lead time of the EEW system is by installing a very robust and rapid communication system to disseminate the warning.

We need further investigation and research about the method with various scenario earthquakes to gain more accurate result on the estimation of EEW system performance, so the performance can be improve to reduce seismic risk in the future. Finally we concluded that future EEW system has a potential to reduce the seismic risk in western Java, Indonesia.

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