A NEW APPROACH TOWARDS EARTHQUAKE EARLY WARNING IN INDIA

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ABSTRACT: Present work introduces a new approach towards early warnings in Earthquake Early Warning (EEW) systems, considering Destructive Intensity (DI) approach as used in Compact UrEDAS of Japan. Further, an empirical correlation relationship is proposed between the earthquake magnitude and the MMI values. Also, the threshold values for magnitude and intensity for EEW are set. The proposed correlation is validated for various recorded and synthetically generated Indian earthquake records. It was found that out of 74 records of magnitude (M) \geq 5, with rock and stiff soil site conditions and epicentral distance <70 km, 66 are correct predictions.

1. INTRODUCTION

Earthquakes are the potential source for large scale moderate to complete damages. Recently developed risk mitigation systems are however able to detect an earthquake in real-time and issue warnings to the vulnerable areas. These are called Earthquake Early Warning systems (EEW).

In this study we introduce the intensity as a parameter for the detection of damaging earthquakes following the principal of Compact UrEDAS of Japan (Nakamura *et al.* 2011). Based on the database considered, a new correlation is proposed between intensity and magnitude of earthquake to setup threshold for correct detection of damaging earthquakes. The proposed correlation is validated considering both the recorded as well as synthetic data generated during various earthquakes in and around of the Himalayan belt.

2. COMPACT UrEDAS

Destructive Intensity (DI) approach was proposed by Nakamura et al., (2011) to determine the strength of an earthquake based on Compact UrEDAS of Japan. It estimates the Destructive Intensity (DI) of the earthquake in real-time and issues early warning if found potential for damages. The Destructive Intensity (DI) was calculated as per Eq. (1) (Nakamura and Saita, 2007);

$$DI = \log|a.v| \tag{1}$$

Where "*DI*" is the Destructive Intensity, "v" is the velocity vector and "*a*" is the acceleration vector. Once the sensors detect the P-wave arrival, the value of DI starts increasing drastically. The peak value of DI achieved within t seconds since P-wave detection is s used as the P wave alarm. Further increase in DI would take place at a slower rate. The DI value shows a further increase, but at a reduced rate. When the S wave arrives, DI reaches its maximum value called the DI_{max}. Nakamura, (2004) proposed a relation between the DI_{max} and the Modified Mercalli Intensity (MMI) as given in Eq. (2). The proposed correlations by Ritcher (1958) Bolt (1993) and Wald (Wald *et al.*1999).

$$MMI = \left(\frac{11}{7}\right)DI + 4.27\tag{2}$$

3. DATA AND ANALYSIS

The analysis consists of collection of Indian earthquake records from PESMOS (http://pesmos.in) with magnitude M≥5. In addition, due to unavailability of large number of recorded data of higher magnitude, additional synthetically generated ground motion records having M \geq 5.5 are also used. All the synthetic ground motions used in this work are taken from Anbazhagan et al., (2013). These ground motions were generated using Finite Fault simulation model for different earthquakes in the Himalayan region. Event details and the validation of each of these synthetic ground motions can be read from Anbazhagan et al., (2013) and are not presented here due to limit in paper length. Hence, the dataset consists of recorded as well as synthetically generated ground motions of M>5 recorded both at rock site or stiff site conditions within epicentral distance <70km. Total number of records satisfying the above criteria are 74. Further, Japanese dataset consisting of records with similar selection criteria as the Indian database, from K-NET (Kyoshin Network) (www.kyoshin.bosai.go.jp) having M≥5 recorded both at rock site or stiff site conditions within epicentral distance < 50km are also used.

The arrival of the P wave at the seismic station is noted for each of these records. Next, the maximum Destructive Intensity (DI) value is estimated as per Eq. (1). This involves integration of acceleration time history to determine the velocity records. Further, the obtained velocity record is then filtered with a highpass Butterworth filter with a cut-off frequency of 0.075Hz to separate low frequency drift. The maximum value of the product of acceleration vector and velocity vector obtained within 3.0s of P wave arrival at the sensor is taken as the DI value and used as P wave alarm by comparing it to the MMI scale as per Eq. (2). This new parameter for issuing of P wave alarm within 3.0s of arrival of the P wave at the sensor is been called the Modified Intensity for P wave alarm (MI-P).

A linear regression is performed using Japanese database to establish correlation between magnitude (M) and MI-P. The average of MI-P values of the same earthquake obtained from four stations closest to the epicenter is taken. The best fitting relationship found between MI-P and M is;

$$MI - P = 1.1684M - 1.8636$$
(3)

Figure 1 shows regression between the MI-P and magnitude (M) values along with the Japanese dataset used in the linear regression. Further, considering Eq. 3, threshold values for magnitude and MI-P are set. Taking magnitude value as 6 and the corresponding MI-P value obtained is 5.15 as per Eq. (3).



Fig. 1 Regression of MI-P with magnitude (M)

4. VALIDATION OF PROPOSED CORRELATION

In order to validate the above proposed correlation and to check the effectiveness in terms of warning, two sets of ground motion records are used. These consist of recorded ground motions from PESMOS and synthetically generated ground motions for M≥5.5 due to unavailability of large number of recorded data for higher magnitudes. Synthetic data were generated by Anbazhagan et al., (2013) using finite fault simulation model. Further these synthetic data were validated with the available records in terms of acceleration time history, Fourier spectra and response spectra at bedrock. Anbazhagan et al., (2013) proposed a regional ground motion prediction equation for the Himalayan region based on combined dataset of recorded as well as synthetic ground motions. Figure 2 shows the magnitude (M) vs. MI-P, P wave alarm plot for recorded and synthetic Indian data with the predetermined threshold values. The first quadrant in Figure 2 consists of the records exceeding both the threshold values (magnitude as well as MI-P) and thus "True alarm" is issued for these records. "False alarm" is issued for the records in the second quadrant, which are of M<6 i.e. not dangerous earthquakes but exceed the MI-P threshold value. The third quadrant consists of records with M<6 and MI-P< 5.15 for which "Correct no alarm" is issued. The records in the fourth quadrant exceed the threshold value of M but not MI-P; it is a case of "Missed alarm" where a

dangerous earthquake remained undetected. Hence, it can be concluded from Figure 2 that majority of the alarms are detected correctly as *True alarm* or *correct no alarm*. The numbers of different P wave alarms issued for Indian earthquake records used in Figure 2 are also presented below in Table 1. It can be observed from Table 1 that out of 74 records, only 8 records are showing *False alarm*.

S. NO.	Alarm type	Number of alarms
1.	True alarm	53
2.	False alarm	8
3.	Correct no alarm	13
4.	Missed alarm	0

Table 1: P wave alarms issued for Indian records

5. CONCLUSION

Intensity of earthquake has been used as an attribute for EEW system to issue early warnings using Indian database. The maximum intensity attained within 3 sec of arrival of the P wave at the sensors is noted and compared to the MMI scale. Out of 74 recorded and synthetically generated Indian earthquakes 66 are correct detections. The use of intensity as a new attribute for EEW systems for Indian earthquakes



Fig. 2 P wave alarm plot for recorded and synthetically Indian data

provided acceptable and satisfactory results. Hence, intensity as an added parameter with the existing parameters can be expected to be used in the future to issue early warning to the Indian subcontinent. It has to be mentioned here that the use of synthetically generated records of greater magnitude and field records of lower magnitude values for validating this new attribute leaves a scope of future study with a wider range of magnitude values for both the databases.

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