Local Site Effects Influence on Earthquake Early-Warning Parameters

A. Mugesh, Aniket Desai, Ravi S. Jakka, and Kamal

Abstract Earthquake early-warning (EEW) system is a valuable device to detect an impending earthquake in real time and helps in the mitigation of seismic risk. The technology of EEW is used for calculating the size of an earthquake based on the first three seconds of recorded P-wave ground motion at the given site. The issues of precision are still challenging in this system. In this paper, an endeavor is made to show the influence of local site effects on earthquake early-warning parameters such as average ground motion period (τ_c) and the peak displacement amplitude (P_d) in the initial three seconds of the motion records. The analysis is carried out using the ground motion records of the Japanese dataset. The vertical component of the acceleration waveforms is used to determine the earthquake early-warning parameters. The comparison is made between the variations of τ_c and P_d parameters with the magnitude τ_c, epicentral distance, and average shear wave velocity for the surface motions. The results indicated that the local site effects significantly influence the earthquake early-warning parameters.

Keywords Earthquake early-warning parameters · Magnitude · Average shear wave velocity · Borehole motion · And surface motion

1 Introduction

In the current scenario, the earthquake early-warning system plays a vital role in the prediction of the most damaging earthquake, but still, it is in developing stage. There were many countries like Japan, Taiwan, and Southern California that provide an early warning during an earthquake was in good agreement with an source parameters of

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the earthquake. But for providing the early warning, there were many parameters used like predominant period, cumulative average velocity, average ground motion period, peak displacement amplitudes, etc. Researchers in this field are still developing new applications for improving the accuracy of the early-warning period in the earthquake early-warning system. In the past and present, there were many early-warning signal parameters are found they are ground motion average period τ_c and peak displacement amplitude P_d and it shows a good improvement for measurement of the earthquake size. During the origin of the earthquake, the early-warning waveform of three seconds time window was taken into account to determine the early-warning parameters like τ_c and P_d. In Taiwan, the experiment conducted for the onsite early-warning approach suggested that both τ_c and the peak displacement amplitude were possible to give a reliable threshold warning during the earthquake and stated that those given parameters had the complement usage for the regional approach in Taiwan [1]. Wu and Zhao [2] clearly explained the earthquake early-warning practice, and peak displacement amplitude provides a more advanced warning period from the three seconds of the early-warning signal. They have shown the magnitude determination from the P_d parameter with lesser uncertainty, and this parameter is used to reduce the false alarms caused by the small and moderate earthquake [3]. For many practical early warning purposes, the considered magnitude was greater than 6 is resulted in a betterment way during the warning period compared with lower size of the magnitude and it suggested that the future work like uncertainties findings in the estimation of magnitude and intensity from the initial P-wave motion. Authors [4, 5] suggested that the relationship between τ_c and M shows a better fit in the regression analysis, and they were used the high-pass filter with a cutoff frequency of 0.075 Hz for removing the noise data in the collected waveform. Wu et al. [6] shows the linear relationship of the τ_c and P_d parameters with the function of the magnitude in the range of 4–8 by using the regression analysis with a better fit of lesser standard deviation. Bhardwaj [7] concluded that the magnitude obtained from the τ_c of the initial P-wave provided a satisfactory solution. The comparison was made between the τ_c and P_d with the function of the magnitude by using linear regression analysis with the considered Indian dataset [8]. The logarithmic τ_c with magnitude shows a better correlation with a positive slope in regression analysis [9]. This study deals with, by comparing the early warning parameters with epicentral distance and the average shear wave velocity were shown the influence of local site effects in the initial P-wave of three seconds time window.

2 Data Analysis

This study considered the bedrock and surface vertical component waveform of the seven individual station records with the single earthquake event. The data were collected in a Japanese strong motion database in KIK-net sensors installed in both borehole and the surface at the sites with a magnitude of 6.7 within the covered epicentral distance of 18 to 66 km. In the considered seven-station records, each

Table 1 List of stations and earthquakes used in this study

Eventname	Station	Latitude	Longitude	Magnitude	Epicentral distance (km)
Eastern an central Iburi	HDKH04	42.5126	142.0381	6.7	18
	IBUH02	42.8714	142.1285		20
	HDKH03	42.5934	142.3521		22
	HDKH01	42.7031	142.2296		26
	IRKH02	43.2204	141.6523		30
	IBUH01	42.8739	141.8191		44
	SRCH09	43.0587	141.8063		66

station has two sets of motion that is bedrock motion and the surface motion, so it covered 14 vertical component of the P-wave motion. The site characterization details were also collected from the KIK-net Web site, it includes the soil profile data for each station, and these collected soil profile data are used to classify the sites based on average shear wave velocity for each site. The earthquake event details are given in Table 1.

3 Methodology

In this study, the waveform data of the vertical component of bedrock and surface acceleration recorded by the KIK-net seismic networks of the National Research Institute for Earth Science and Disaster Prevention (NIED-Japan) are used. The selected stations are near to the epicenter, and the collected data for each station show an uncorrected value of the acceleration records, so here linear baseline correction is carried out by using SeismoSignal software for the betterment of the results. The value of τ_c and P_d has been determined at the level of bedrock and the surface motion for each station record. Then, the site classification is made for the selected sites based on average shear wave velocity followed by NEHRP [10].

4 $\tau_{c\ \mathrm{and}}$ P_d Method

Toward finding the magnitude of the earthquake, it is essential to describe whether the occurrence of slip motion is stationary or it is still developing, which is usually revealed in the period of the primary motion. The minor events produce a short period, and the extended events yield a longer period of the initial motions, respectively. Normally, the slip motion is a difficult measurement, and also, a large event often begins with a short period, followed by a long period motion. Accordingly, it is significant to define the average period during the first motion. τ_c is a measurement of the average period of the ground motion with a three-second time window of P waves developed [1]. τ_c is determined as

$$\tau_c = \frac{2\pi}{\sqrt{r}}$$

where $r = \frac{\int_0^{\tau_0} \dot{u}^2(t)\mathrm{d}t}{\int_0^{\tau_0} u^2(t)\mathrm{d}t}$, $\tau_0 =$ duration of the time window (generally 3 s),

$\dot{u}(t) =$ velocity and $u(t) =$ vertical displacement obtained from ground motion record on double integration.

P_d is the peak displacement amplitude in the first three seconds after the arrival of P waves, it is the robust measurement for determining the magnitudes of earthquakes, and it has practical application in the earthquake early-warning systems [2].

5 Results and Discussions

5.1 *Variation of τ_c in bedrock and Surface motion*

The motion at the base of the soil deposit (also the top of the rock) is known as bedrock motion, and the free surface in the top of the soil deposit is known as surface motion. The acceleration data were collected from the Kiban Kyoshin network (KIK-net) strong motion seismograph network, which consists of pairs of seismographs installed in a borehole and surface at a different site. In the borehole and the surface, the recorded motion was considered as a bedrock and surface motion for the analysis. The collected acceleration data are not about the zero axis line, so here the baseline correction analyses were carried out in the SeismoSpect software v18, and these records were integrated to obtain velocity and displacement. A bandpass second-order Butterworth filter with cutoff frequency 0.07–30 Hz was applied on the record to remove the low-frequency drift in the velocity and displacement signal. The average ground motion period (τ_c) and the peak displacement amplitude (P_d) for the bedrock and the surface motion estimated with the selected time window of the 3 s.

In Fig. 1, the comparison is made for logarithmic τ_c of bedrock and surface motion with different sites for the magnitude of 6.7. The surface motion early-warning parameter shows higher than the bedrock motion parameter for all sites. It represents that the surface amplification is higher than the bedrock amplification due to softer soil conditions in all sites.

The logarithmic parameter τ_c increased with increasing epicentral distance. Figure 2 represents that the surface motion parameter is high compared to the bedrock motion parameter, and it reveals that with the increasing epicentral distance, the surface motion parameter is increasing. And also, it shows that the surface motion has a higher difference with a distance greater than 35 km due to site effects.

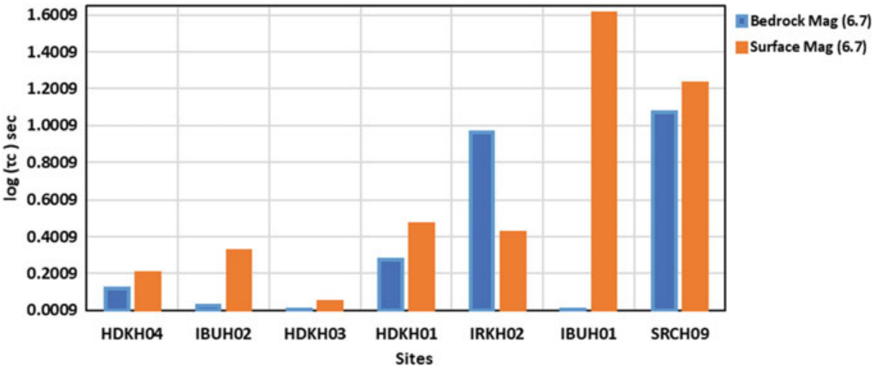

Fig. 1 τ_c recorded at different sites for the considered earthquake of magnitude 6.7

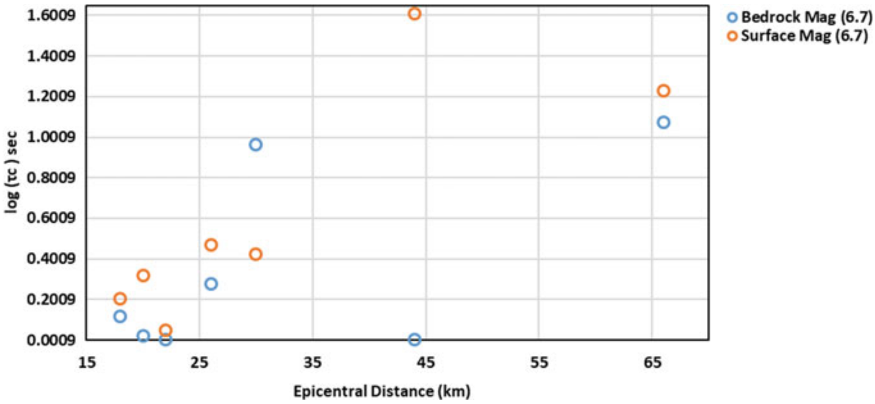

Fig. 2 Variation of $\log(\tau_c)$ with epicentral distance

5.2 *Variation of P_d in Bedrock and Surface Motion*

The logarithmic peak displacement amplitude of the early-warning parameter P_d is compared with the different sites with a magnitude of 6.7 in Fig. 3. It shows that most of the site surface motion parameter is lower than the bedrock motion parameter, the observation made in P_d has very low-level amplitudes that were represented in negative log parameter, and the positive P_d parameter reflected as a higher amplitude due to the considerable soil amplification. The site IBUH01 has a higher surface motion parameter than the bedrock motion parameter, and it may due to high-level amplification of the motion.

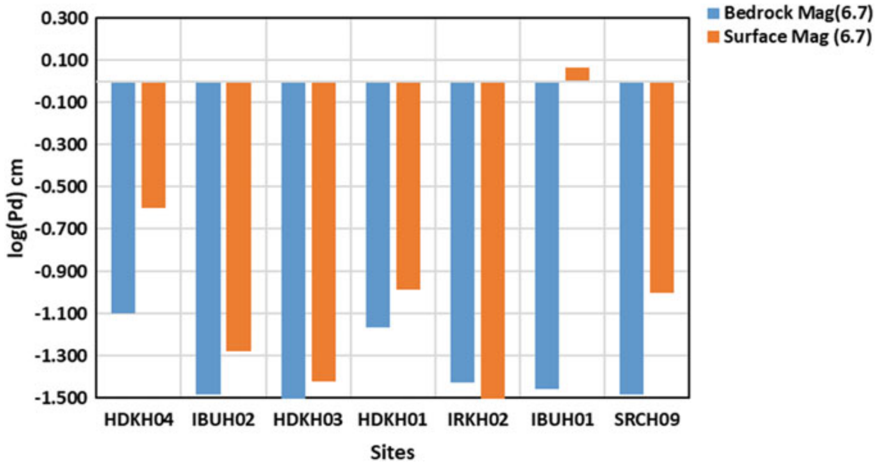

Fig. 3 P_d recorded at different sites for the considered earthquake of magnitude 6.7

5.3 τ_c on the Different Type of Sites Based on the Average Velocity of the Shear Wave

The wave propagation theory clearly explains that the surface motion amplitude depends on the density and shear wave velocity of the subsurface material. Generally, in-situ density has a relatively smaller variation with depth. So, here the shear wave velocity plays an important part in representing the soil site effects. According to National Earthquake Hazard Reduction Program (NEHRP) and Uniform Building Code (UBC), the average shear wave velocity has been calculated by

$$\text{Average Shear wave velocity}(V_s) = \frac{\sum \mathrm{d}i}{\sum \frac{\mathrm{d}i}{Vi}}$$

di—thickness of soil layers (m)

Vi—shear wave velocity of the soil layers (m/s) (Table 2).

5.3.1 Influence of Average Shear Wave Velocity on τ_c and P_d for Surface Motion

The average shear velocity is one of the most vital properties in the site effect characterization. In Fig. 4, the logarithmic parameter of τ_c is compared with the function of average shear wave velocity and it states that log τ_c is decreased with increasing average shear wave velocity, and also it shows the site which has the lowest shear wave velocity, there the τ_c parameter shows the highest value in the surface motion.

Table 2 Site Classification based on Average Shear-wave Velocity

Site	Average Shear Wave Velocity (m/s)	Site Class	Site Type
HDKH01	426	C	Very dense soil or soft rock
HDKH03	732	C	Very dense soil or soft rock
HDKH04	509	C	Very dense soil or soft rock
IBUH01	408	C	Very dense soil or soft rock
IBUH02	733	C	Very dense soil or soft rock
IRKH02	588	C	Very dense soil or soft rock
SRCH09	221	D	Stiff soil

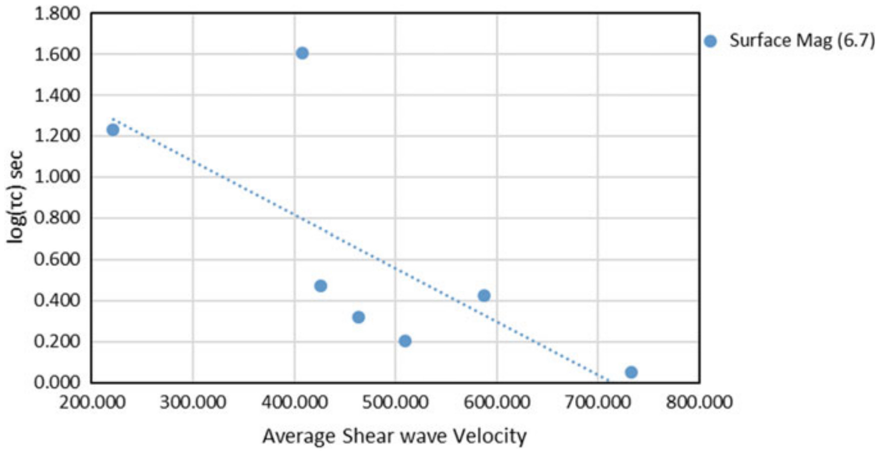

Fig. 4 Variation of τ_c with average shear wave velocity of the site

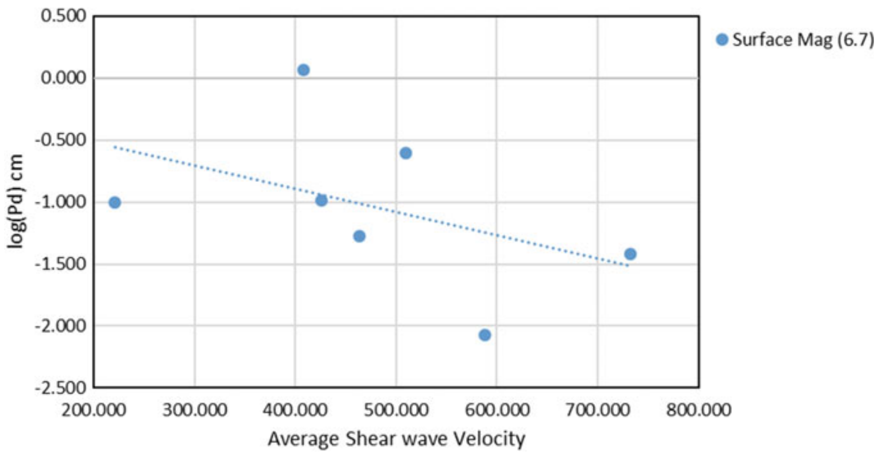

Fig. 5 Variation of P_d with average shear wave velocity of the site

The logarithmic parameter of P_d is compared with the function of average shear wave velocity (Fig. 5). The above mentioned graphical representation explains that the log P_d is decreased with increasing average shear wave velocity, and also it shows the site which has the lowest shear wave velocity, there the P_d parameter shows the highest value in the surface motion.

6 Conclusions

This work endeavored to study the effects of local site conditions on earthquake early-warning parameters of the bedrock and the surface motion. The sites considered in this study show the increment in the early-warning parameters τ_c and P_d for the surface motion compared to bedrock motion irrespective of the magnitude of an earthquake. Similarly, the τ_c parameter is increasing in surface motion compared to the bedrock motion with respective epicentral distance. The increase in τ_c and P_d values in the surface motion is certainly due to soil amplification. There is a decrease in the value of τ_c and P_d parameters with an increase in the average shear wave velocity of the site. The site which has the lowest average shear wave velocity shows the highest increment of the early-warning parameters of τ_c and P_d. It reflects that the sites which have the soft soil type show higher amplification in earthquake early-warning parameters. But further studies are needed for justifying the relationship between the modifications of early-warning parameters with a change in the average shear wave velocity and the epicentral distance of the site.

References

1. Wu YM, Kanamori H (2005) Experiment on an onsite early warning method for the Taiwan early warning system. Bull Seismol Soc Am 95(1):347–353. https://doi.org/10.1785/0120040097
2. Wu YM, Zhao L (2006) Magnitude estimation using the first three seconds P-wave amplitude in earthquake early warning. Geophys Res Lett 33(16):4–7. https://doi.org/10.1029/2006GL026871
3. Wu YM, Kanamori H, Allen RM, Hauksson E (2007) Determination of earthquake early warning parameters, τ_c and P_d, for southern California. Geophys J Int 170(2):711–717. https://doi.org/10.1111/j.1365-246X.2007.03430.x
4. Wu YM, Kanamori H (2008) Development of an earthquake early warning system using real-time strong motion signals. Sensors 8(1):1–9. https://doi.org/10.3390/s8010001
5. Shieh JT, Wu YM, Allen RM (2008) A comparison of τ_c and T_p max for magnitude estimation in earthquake early warning. Geophys Res Lett 35(20):1–5. https://doi.org/10.1029/2008GL035611
6. Wen KL, Shin TC, Wu YM, Hsiao NC, Wu BR (2009) Earthquake early warning technology progress in Taiwan. J Disaster Res 4
7. Bhardwaj R (2012) Analysis of Tauc (t_c) and P_d attributes for earthquake early warning in India. In: 15th world conference on earthquake engineering (15WCEE)

8. Shanyou L, Jindong S (2008) A new magnitude estimation method based on predominant period and peak amplitude. 14 WCEE. ftp://128.46.154.21/spujol/Andres/files/S05-03-012.PDF
9. Zhang J, Li H (2018) Testing and comparison of three frequency-based magnitude estimating parameters for earthquake early warning based events in the Yunnan region, China in 2014. J Geophys Eng 15(3):971–979. https://doi.org/10.1088/1742-2140/aaa85d
10. NEHRP Recommended seismic provisions for new buildings and other structures FEMA P-750/2009 Edition