Study of Local Site Effects on Earthquake Early Warning

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Abstract. One of the key information required for earthquake disaster mitigation and management is the prior understanding of the impact of strong ground motion. The Earthquake Early Warning system (EEW) is one of the upcoming instruments to effectively reduce the seismic risk and it provides an alert of imminent damage by quick determination of earthquake source parameters based on the simple onsets. The issues of improving accuracy and applicability are still controversial. In this paper, an attempt has been made to show the influence of local site effects on the earthquake early warning on strong ground motion parameters. The most commonly used EEW parameter, the average period of the initial 3 seconds of the ground motion records has been used. The analysis has been carried out with the basis of existing measurable ground motion records from the Japanese dataset. The results showed how the earthquake early warning parameter varies for different bedrock motions, surface motions and also for different site classes. It indicates that the local site effects are significantly influencing the earthquake early warning parameter considered.

Keywords: Early Warning Parameter, Magnitude, Bedrock, Soil surface motion, Shear wave velocity.

1 Introduction

In an existing scenario, various advanced tools and technology have been developed for predicting the earthquake, but at the same time there is a need for premature mitigation in an earthquake disaster for this, the earthquake early warning system plays a vital role in the mitigation practice. The onsite early warning approach deals with the foundation measure of the primary wave observed at a site is used to forecast the ensuing Shear and Surface-wave at a similar site and the measure of P- wave frequency-dependent parameter is τ_c by considering the first 3 seconds of P- wave data. The results [1] made between τ_c and M_w parameters, it shows a better fit trend with good relationship determined by data collected from Japan, Taiwan, and Southern California. Seismic waves with the longer period energy were prompted by huge slip along the fault plane in larger events and waves with small period energy produce the lesser amplitude were caused by minor earthquakes, thus Primary wave period and the amplitude in the vertical movement waveforms could be used for evaluating the earthquake magnitude rapidly [2]. Earthquake early warning disseminates an event magnitude information previously the onset of robust shaking, thus it gives time to mitigate. Prompt magnitude assessment from EEW will lead to improving disaster mitigation and management in extreme seismic areas [3]. A prediction was made and it compared with the worldwide predicted relationships of τ_c - M and P_d – M with the better fit regression has also been estimated for the Indian region [4].

During an earthquake, the local site effects can greatly influence all of the significant characteristics such as amplitude, frequency content, and duration of strong ground motion. The extent of their efficiency is influenced by the geometry and the geological conditions of the subsurface resources, onsite features, and velocity of the shear wave and the physical characteristics of the input motion. The ground response analysis illustrates the nature of the local site effects for the sites which have different surface and subsurface motions. [5]. 1D Equivalent linear ground response analysis using a computer-based program namely DEEP SOIL v7 [10] is used. In the soil column during the propagation of the seismic waves the modification in amplitude, frequency content and duration leads to the site effects [7]. The softer soil subjected to the strong motions has every possibility to show a large residual strain at the end of such seismic events [6]. In the present study, we have explored the influence of varying earthquake early warning parameter such as ground motion period (τ_c) in a bedrock level and soil surface level.

2 Data Analysis

In this study, the vertical components of 26 individual station records of 6 events have been used. The data was collected in a Japanese strong motion database in KIK-net seismic networks for the period of 2014 to 2019 and the range of magnitude between 6.1 to 6.6 within the covered epicentral distance of 11 km to 121 km.

Fig. 1. Location of KIK-net stations and earthquake events considered: The epicenters of the earthquakes are shown in Red stars and the KIK-net stations are shown in Yellow Triangles.

Table 1. List of stations and earthquakes used in this study

EventName	Station	Latitude	Longitude	Magnitude	Epicentral Distance (Km)
Central Tottori (2016)	-	35.380	133.850	6.6	0
	OKYH09	35.180	133.676		27
	TTRH03	35.355	133.491		33
	OKYH11	35.073	134.116		42
	TTRH02	35.231	133.390		45
	HYGH03	35.219	134.523		63
	HRSH03	34.518	133.137		116
Northern Osaka (2018)	-	34.843	135.622	6.1	0
	OSKH04	34.763	135.705		12
	OSKH02	34.662	135.389		29
	SIGH03	34.853	136.031		37
	NARH06	34.641	136.051		45
	HYGH09	34.908	135.084		50
Western Shimane (2018)	-	35.180	132.590	6.1	0
	SMNH04	35.091	132.530		11
	SMNH03	35.224	132.722		13
	SMNH05	34.869	132.639		35
	SMNH06	34.883	132.202		48

	HRSH10	34.747	132.379		52
	SMNH07	34.694	132.040		74
	HRSH03	34.518	133.137		89
Hyugnada (2019)	-	31.800	131.970	6.3	0
	MYZH08	32.213	131.530		62
	MYZH10	32.021	131.290		69
	MYZH11	32.020	131.470		53
	MYZH13	31.730	131.079		85
	MYZH15	32.365	131.589		72
Kumamoto (2016)	-	32.740	130.810	6.5	0
	KMMH02	33.122	131.062		48
	KMMH03	32.998	130.830		28
Iyonada (2014)	-	33.690	131.890	6.2	0
	EHMH02	33.865	133.184		121

3 Methodology

In this study, the waveform data of the vertical component of the acceleration recorded by the KIK-net seismic networks of the National Research Institute for Earth Science and Disaster Prevention (NIED- Japan) is used. The selected stations are near to the epicenter and the collected data for each station shows an uncorrected value of the acceleration records, so here linear baseline correction is carried out by using Seismo Signal software for the betterment of the results. The value of τ_c has been determined at the level of bedrock motion for each individual station record. After obtaining the bedrock motion the 1D Equivalent linear ground response analysis was carried out by using DEEPSOIL v7 software for determining the response of the soil surface motion. For finding the soil response, the local site soil profiles were collected in KIK-net records, it includes depth, layer thickness and shear wave velocity profiles for each site. Once the soil surface motion has been obtained in that, the τ_c parameter has been determined.

3.1 τ_c Method

Towards 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 the 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 time 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 [8]. τ_c is determined as

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

Where, $r = \frac{\int_0^{\tau_0} \dot{u}^2(t)dt}{\int_0^{\tau_0} u^2(t)dt}$, τ_0 = duration of the time window (generally 3 sec),

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

4 Results and Discussions

4.1 Variation of τ_c in bedrock motion

The motion at the base of the soil deposit (also the top of the rock) is known as bedrock motion. The acceleration data was collected from the KIK-net (Kiban Kyoshin network) is a strong motion seismograph network, which consists of pairs of seismographs installed in a borehole. In the borehole, the recorded motion was considered as a bedrock motion for the analysis. The range of acceleration varies from 3.0 gals to 114 gals for all sites. The collected acceleration data is not with reference to the zero axis line, so here the baseline correction analyses were carried out in the Seismo-Signal software v16 and these records were integrated to obtain velocity and displacement. A high pass fifth-order Butterworth filter with cutoff frequency 0.08 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) for the bedrock motion was estimated with the selected time window of the 3 seconds.

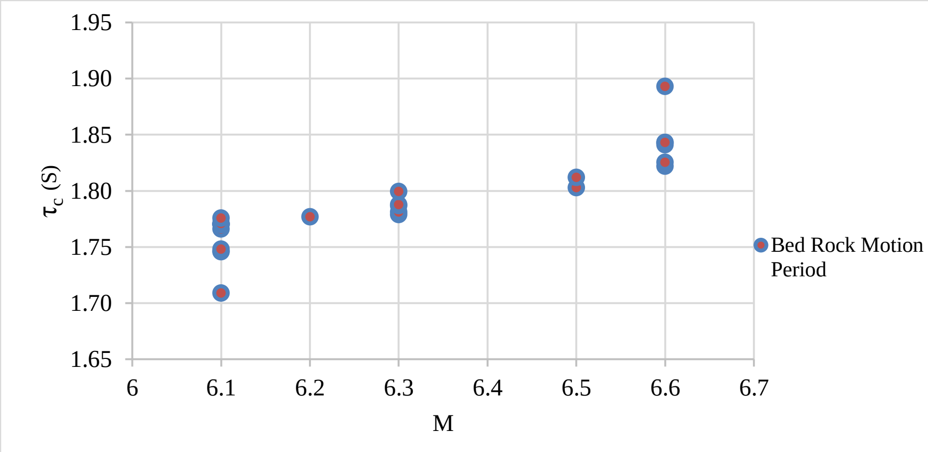

Fig. 2. τ_c measurements from 26 sites vs magnitude for bedrock motion

Figure 2 shows the τ_c determined from the 26 records plotted by the function of Magnitude (M). It indicates that the τ_c increases with increasing magnitude and for all sites the ground motion average period is greater than one second ($\tau_c > 1s$), it means that the event is potentially damaging and it provides a useful threshold warning for the larger earthquakes (M > 6). For predicting the uncertainties in any ground motion parameters, the regression analysis is the better solution.

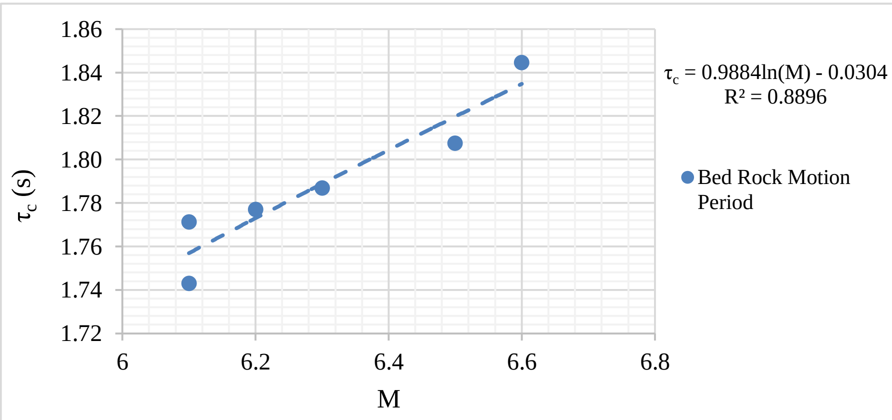

Fig. 3. Average τ_c for six events vs magnitude for bedrock motion

Figure 3 shows an average value of τ_c for each event, the blue dashed line shows that the logarithmic regression is increasing linearly and the magnitude 6.6 (Central Tottori-2016) shows 0.10 times of greater than the magnitude 6.1 (Northern Osaka – 2018). Here the regression relationships in a logarithmic term were made for both coordinates M and τ_c and it gives a better correlation between the magnitude and bedrock motion average period.

$$\tau_c = 0.9884 \ln(M) - 0.0304 \quad (1)$$

$$M = 10.243 \ln(\tau_c) + 0.3472 \quad (2)$$

4.2 Variation of τ_c in surface motion

The motion at the surface of the soil deposit is known as surface motion. For obtaining surface motion the one-dimensional ground response analysis has been carried out by using the software DEEPSOIL v7. The equivalent linear method was followed in the analysis to obtain the response of the soil and the soil properties like thickness, unit weight and shear wave velocity of the soil layers are collected from the KIK-net soil condition database. The acceleration data collected from borehole sensors of the KIK-net was considered as an input motion. The final output of surface motion time histories was obtained. The range of soil surface acceleration varies from 3.2 gals to 30 gals for all sites. Afterward, the time window of the 3 seconds motion was selected to calculate the average ground motion period (τ_c) for the surface motion.

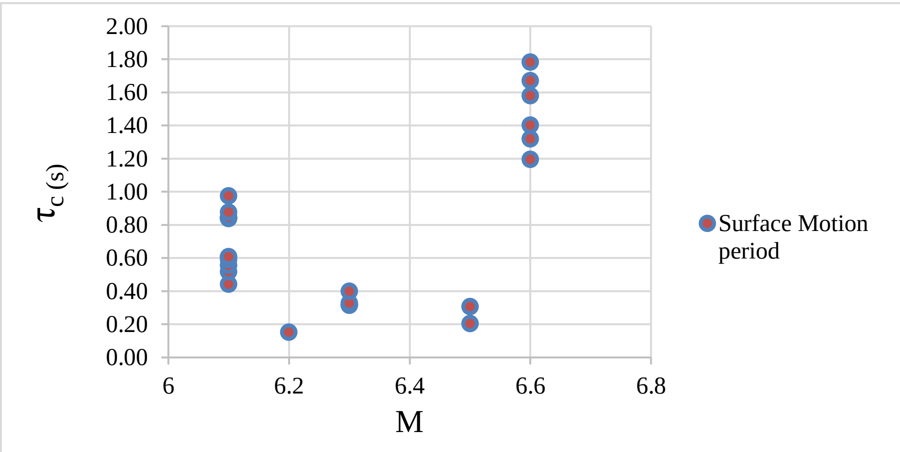

Fig. 4. τ_c Measurements from 26 sites vs magnitude for surface motion

Figure 4 shows the τc determined from the 26 records plotted as a function of Magnitude (M). It indicates that the sites which are having a magnitude 6.6 show the surface motion average period greater than one second (τ_c > 1s), it means the event is potentially damaging and it provides a useful threshold warning for the larger earthquakes (M > 6). For the sites which come under the magnitude range 6 to 6.5, the average period is less than one second (τ_c < 1s). This means that the event has already ended or is not likely to grow beyond M > 6 [1].

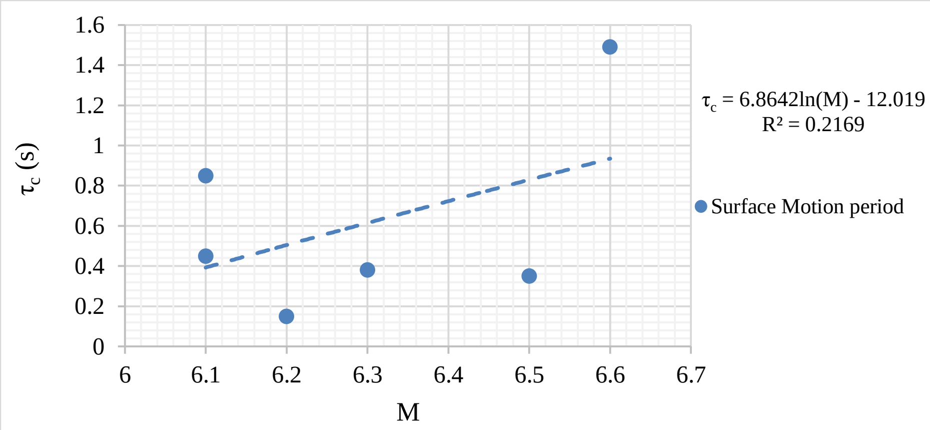

Fig. 5. Average τ_C for six events vs magnitude for surface motion

Figure 5 shows an average value of τc for each event, the blue dashed line shows that the logarithmic regression is increasing linearly. Also, the value of Tc for magnitude 6.6 (Central - Tottori-2016) is 1.05 times that of magnitude 6.1 (Northern Osaka - 2018). Here, the regression relationships in a logarithmic term were made for both M and τ_c. It gives the weak correlation (due to the smaller value of the data) between the magnitude and surface motion average period.

$$\tau c = 6.8642\ln(M) - 12.019 \quad (3)$$

$$M = 0.0935\ln(\tau c) + 6.3697 \quad (4)$$

4.3 τc 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 [9].

4.3.1 Site Classification

According to NEHRP (National Earthquake Hazard Reduction Programme) and UBC (Uniform Building Code), the seismic site classification has been carried out based on the average shear wave velocity and it has been calculated by,

$$\text{Average Shear wave velocity (Vs@30m)} = \frac{\sum \text{di}}{\sum \frac{\text{di}}{\text{Vi}}}$$

$$di - \text{thickness of soil layers (m)}$$
$$Vi - \text{Shear wave Velocity of the soil layers } (^{m}/_{s})$$

4.3.2 Influence of Average Shear wave velocity on ground motion average period (τ_c) for Surface motion

Figure 6 represents the variation in the ground motion average period for surface level based on the shear wave velocity. Here, the site classes D, C, and B show the gradual increment in the surface motion period. Compared to all other sites, the site class B shows the maximum average shear wave velocity 974.83 m/s. Therefore, the ground motion average period for surface level is higher for site class B compared to other site classes.

Fig. 6. Variation of average τ_C for different site classes

Table 2. Site classification based on average shear wave velocity

S. No	Site Class	Sites	Site Profile Name	Average Shear-wave Velocity (m/s)
1	B	OKYH11	Rock	974.83

		SMNH05		
		MYZH15		
2	C	OKYH09	Very Dense Soil & Soft Rock	601.10
		TTRH03		
		HYGH03		
		HRSH03		
		OSKH04		
		OSKH02		
		SIGH03		
		NARH06		
		HYGH09		
		SMNH03		
		SMNH06		
		HRSH10		
		SMNH07		
		HRSH03		
		MYZH08		
		MYZH10		
		MYZH11		
		MYZH13		
		KMMH02		
		KMMH03		
3	D	TTRH02	Stiff Soil	302.93
		SMNH04		
		EHMH02		

Conclusions

This study shows the effects of local site conditions on earthquake early warning parameter of the bedrock and the surface motions. The site classification is carried out for the collected KIK- net sites in Japan using the calculated average shear wave velocity as per NEHRP and UBC. The site response analysis has been carried out to get the surface motion. The calculated period for the bedrock and the surface motion shows increment with increasing magnitude. Results also showed that the ground motion average period is increased with an increase in the shear wave velocity of the site. However, more detailed studies are needed to verify these outcomes and to develop a relationship between τ_c and avg. shear wave velocity of a site. All the surface motions for earthquake magnitude 6.6 showed the EEW parameter, τ_c value more than one irrespective of site class. We can thus conclude that the impending earthquake would be a damaging one if τ_c is more than 1 irrespective of site class where ground motion is recorded.

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