NEW MAGNITUDE SCALING RELATION FOR EARLY WARNING IN TEHRAN

Mohammad SASANI
PhD Student, International Institute of Earthquake Engineering and Seismology, Tehran, Iran
m.sasani@iiees.ac.ir

Mohammad Reza GHAYAMGHAMIAN
Associate Professor, International Institute of Earthquake Engineering and Seismology, Tehran, Iran
mrgh@iiees.ac.ir

Anooshiravan ANSARI
Assistant Professor, International Institute of Earthquake Engineering and Seismology, Tehran, Iran
a.ansari@iiees.ac.ir

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ABSTRACT

Tehran city, the capital of Iran, is located in the southern part of Alborz mountains in north of Iran, which is a very prone area to earthquake. The recent developments in early warning systems encourage its application for seismic hazard mitigation, especially in mega-cities like Tehran. Here, an effort was made to develop a new relation for magnitude estimation using the initial few seconds of the earthquake rupture. Among several methods applied for such purposes, the estimation of average ground motion period in a 3 sec time window from the beginning of an earthquake record (τ_c) is the most applicable and reliable one.

In this study, the earthquake data in Alborz region recorded by Road, Housing and Urban Development Research Center are collected from 1995 to 2013. The 218 data with magnitude larger than 4.7 are selected for τ_c estimation. Then, the P-wave arrival is picked visually for each record. The τ_c was computed for three different time windows of 2, 3 and 4 seconds after the P-wave arrival. Next, the new scaling relation between τ_c and magnitude (M_w) is developed. The results show that at least a 3 second time window after the P-wave arrival is needed for reliable estimation of magnitude by using τ_c. Furthermore, the developed relation is compared by those introduced by Wu and Kanamori (2005b), Kanamori (2005) and Heidari et al. (2013), which show a good agreement by the Wu and Kanamori's relations. Meanwhile, it shows a clear difference with Heidari et al. relation. This could be attributed to their used data, which were limited to the low magnitude data with Mw lower than 4.6.

INTRODUCTION

Concurrent with the development of urbanization, earthquake hazards pose serious threats to lives and property in urban areas. For seismic hazard mitigation, a practical earthquake forecast method appears to be far from realization, because of the extreme complexity involved in earthquake processes (e.g., Kanamori et al., 1997), but another approach to mitigate seismic hazards is the development of early warning systems (EWS) (Allen, 1978; Allen and Kanamori, 2003; Nakamura, 1988; Wu and Kanamori, 2005a). An EWS provides a few seconds to tens of seconds of warning time for impending ground motions, allowing for mitigation measures in the short term.

Nakamura (1988) first used the frequency content of the initial few seconds of P-wave arrivals. He suggested that larger events cause initial ground motion with longer periods than smaller events. Based on this outcome, the researchers used two important parameters to estimate magnitude of an earthquake in early stages of rupture. The first parameter is dominant ground motion period ($\tau_P^{\max}$) (Allen and Kanamori, 2003; Olson and Allen, 2005), and the second is average ground motion period (τ_c) (Kanamori, 2005; Wu and Kanamori, 2005a, 2005b). Recently, new methods such as artificial neural networks (Bose, 2006), virtual seismologist (Cua, 2005; Yamada, 2007) and slip-weakening distance of near-fault records (Ghayamghamian et al., 2014) have been also developed for such purpose.

In this study, an attempt is made to develop a new magnitude scaling relation for EWS using τ_c method based on earthquake data recorded at Alborz seismotectonic zone. Due to the complicated tectonic nature of Iran, seismic activity is not uniform in the entire region. The highly seismogenic zones of Alborz and Kopet Dagh, extending along the northern borders of Iran and Afghanistan, constitute a part of the northern limit of the Alpine-Himalayan orogenic belt. These zones make contact with the stable Turan platform (Eurasia) to the north (Berberian, 1976a, 1976b). Heidari et al. (2013) made an effort to estimated magnitude scaling relation using τ_c for Tehran City. Their employed database was limited to the earthquake data with magnitudes lower than 4.6, which was the main obstacle in their analysis. They tried to overcome this limitation by combining the earthquake data of large magnitudes from other countries such as United State of America, Japan and Taiwan with those of low magnitudes recorded in Tehran. Meanwhile, this may not be an ideal approach due to special seismigenic features and seismicity of Alborze region, which is even different among other seismotectonic zones in Iran (ex. Zagrous or Kopet Dagh seismotectonic zones). To overcome this deficiency and examine the applicability of such approach, the data recorded by Road, Housing and Urban Development Research Center (RHUDRC) in Alborz region is used here. These data are collected among 81 RHUDRC stations with magnitude larger than 4.7, and covered a magnitude range of 4.8 to 6.5 in a distance range of 90 km from 1995 to 2013. Since τ_c observations from waveforms at individual stations exhibit large variability probably due to measurement error, site effects and path effects (Olson and Allen, 2005), Therefore, the mean of τ_c observations for each event is used in deriving magnitude scaling relation. Finally, the introduced relation is compared with those in national and international scales.

MAGNITUDE ESTIMATION BASED ON τ_c METHOD

This method was first introduced by Kanamori (2005), which is a modified version of the method originally developed by Nakamura (1988). The period parameter τ_c is calculated from the first several seconds of P-wave data. First the parameter, r, should be computed as:

$$r = \frac{\int_0^{t_0} \dot{u}^2(t)dt}{\int_0^{t_0} u^2(t)dt} \tag{1}$$

where $u(t)$ and $\dot{u}(t)$ are ground-motion displacement and velocity, respectively. The integration is over the time interval *(0,t₀)* after the onset of the P-wave and t_0 is set at 2, 3, 4 seconds. Using Parseval's theorem,

$$r = \frac{4\pi^2 \int_0^{\infty} f^2 \left|\hat{u}(f)\right|^2 df}{\int_0^{\infty} \left|\hat{u}(f)\right|^2 df} = 4\pi^2 \left\langle f^2 \right\rangle \tag{2}$$

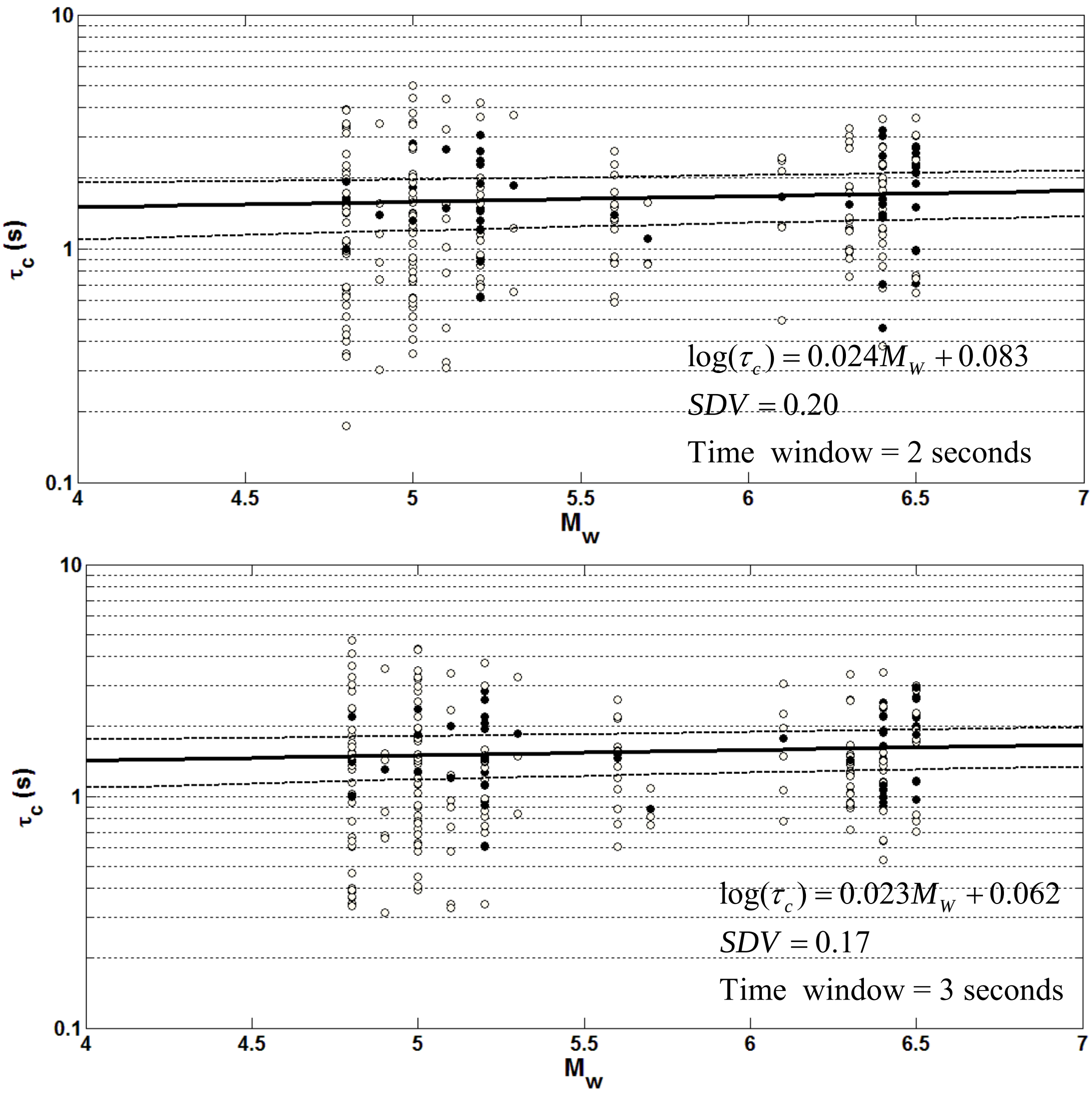
where f is the frequency, $\hat{u}(f)$ is the frequency spectrum of *u(t)* and $\left\langle f^2 \right\rangle$ is the average of f^2 weighted by $\left|\hat{u}(f)\right|^2$. Then, τ_c is:

$$\tau_c = \frac{2\pi}{\sqrt{r}} \tag{3}$$

Small and large events yield short- and long-period initial motions, respectively. However, the slip motion is in general complex, and even a large event often begins with a small short-period motion, followed by a long period motion. Consequently, it is important to define the average period during the first motion, instead of the period of the first motion (Kanamori, 2005). So, τ_c is large for events enriched with low frequency energy in the beginning.

DATA AND ANALYSIS

Since the main goal of EWS is to alarm the catastrophic earthquakes, 55 events in Alborz region with magnitude larger than 4.7 are selected. These events consist of 218 records and occurred during the period from 1995 to 2013. All records are accelerations and their signals are digitized at 200 samples per second. Vertical component strong motion records were used in this study. Input signals were integrated twice to displacement records. To remove the low-frequency drift after integration, a 0.2 Hz high-pass Butterworth filter was applied. The time of P-wave arrival is determined manually for all records, and three time windows of (2, 3 and 4 seconds) are assumed in calculating of the τ_c as shown in Fig. 1.



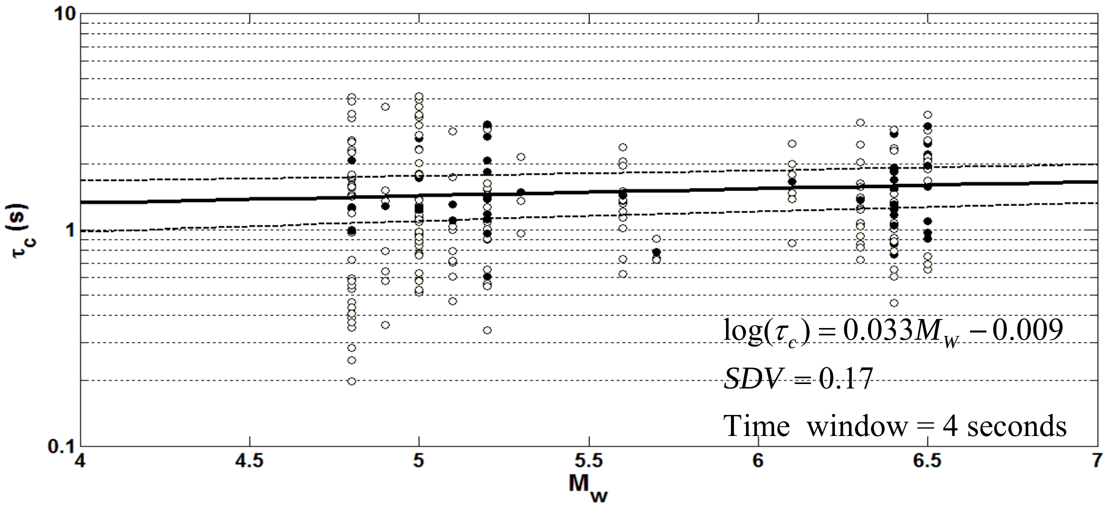


Figure 1. τ_c measurements from records (grey circles) versus Mw; Black circles show the average for the events

Based on the results which are shown in Fig. 1, the relation between τ_c and M_W is calculated with 3 seconds time window as:

$$\log(\tau_c) = 0.023M_W + 0.062 \tag{4}$$

or conversely, magnitude of Alborz region earthquakes can be estimated as:

$$M_W = 43.478\log(\tau_c) - 2.696 \tag{5}$$

To examine the validity of the developed relation in Eq. (5), it is compared with that of proposed by Wu and Kanamori (2005b) for 26 events in the Taiwan region as

$$\log(\tau_c) = 0.179M_W - 0.932 \tag{6}$$

, and is shown in Fig. 2. From this figure, the difference in the slopes of two lines can be observed. This may be caused by the difference in the low frequency limit of high-pass filter for removal of low-frequency modulation. We examine different limits of high-pass filter for accurate estimation of velocity and displacement. The value of 0.2 Hz is found to be the most appropriate one for accurate high-pass filtering of all the records.

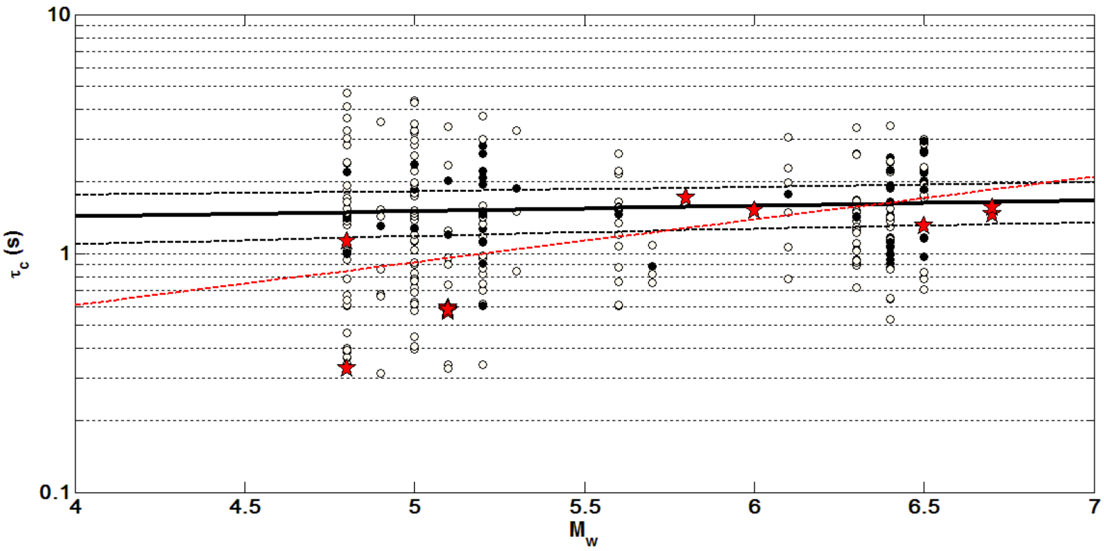


Figure 2. Comparing the results of this study (solid black line) with Wu and Kanamori (2005) relation (thick dashed red line) and Kanamori (2005) estimation of average period (red stars)

This means the removal of periods larger than 5 seconds from the records. Furthermore, Kanamori (2005) used the same method to determine τ_c by using the records of the events listed in Table 1 with magnitude in the range of 2.5 to 8.0 as shown by red stars in Fig. 2. These estimations are found to be in good agreement with our relation mostly in the magnitude range of 4.5 to 6.7.

Table 1. List of events and estimated τ_c from close-in records (Kanamori, 2005)

Event	Date	M_W	τ_c
Taokachi-Oki	9/26/2003	8	4.96
Chi-Chi	9/21/1999	7.6	3.74
Landers	6/28/1992	7.3	1.83
Hector-Mine	10/16/1999	7.1	1.41
Miyagi-Oki	5/26/2003	7	2.15
Tottori	10/6/2000	6.7	1.45
Northridge	1/17/1994	6.7	1.56
San Simeon	12/22/2003	6.5	1.3
North Miyagi	7/26/2003	6	1.51
Sierra Madre	6/28/1991	5.8	1.7
Anza	10/31/2001	5.1	0.57
Big Bear	2/22/2003	5.1	0.59
Big Bear	2/10/2001	5.1	0.58
Pasadena	12/3/1988	4.8	0.33
Coso	7/17/2001	4.8	1.12
Northridge	1/14/2001	4.3	0.34
N. Hollywood	9/9/2001	4.3	0.58
Lucern	7/15/2003	4.2	0.26
Northridge	1/14/2001	4	0.29
Compton	10/28/2001	4	0.4
San Simeon	9/27/2001	2.8	0.24
Running Springs	5/9/2003	2.6	0.12
San Simeon	5/22/2003	2.5	0.22

In Fig. 3, the introduced relation is also compared with the one developed by Heidari et al. (2013) as:

$$M_L = 8.6\log(\tau_c) + 8.8 \quad (7)$$

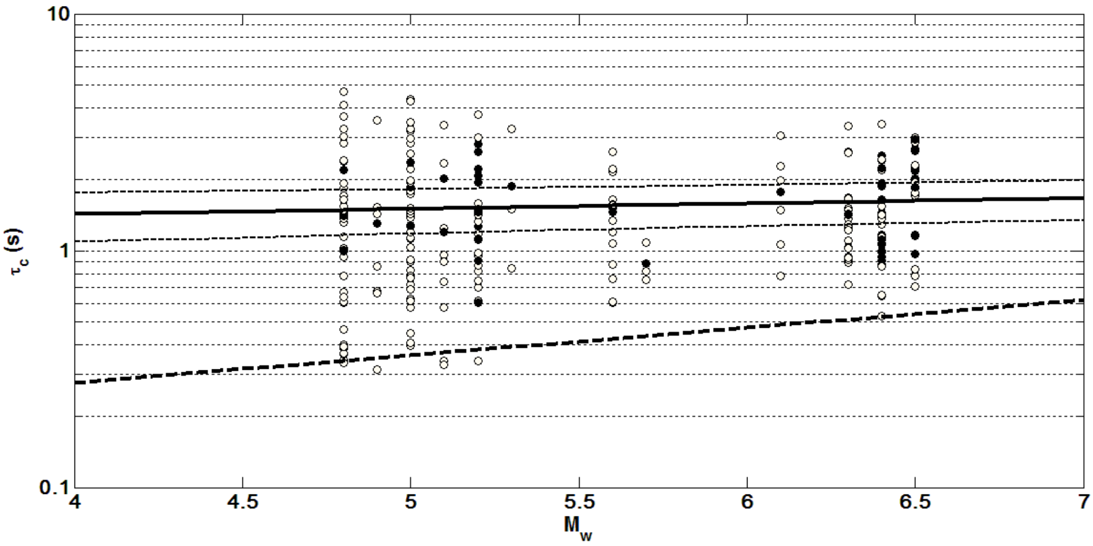


Figure 3. Comparing the results of this study (solid black line) with Heidari et al. (2013) relation (thick dashed line)

This relation is based on 194 events in the magnitude range of 2.5 to 4.6 and in a epeicentral distance of about 80 km from Tehran city. They claim that the relation in Eq. (7) is applicable to the modrate earthquakes in spite of the magnitude limitation in their employed data. Then, we used Eq. (7) to estimated magnitude in the range of 4.8 to 6.5 in compare with our relation (Eq. (5)) in Fig. 3. As shown in this figure, the magnitude is overestimated by using Eq. (7). This show that the magnitude can not be relaibly estimate by Eq. (7) probably due to the magnitude limitation of the employed data. This also verifies the importance of earthquake specifications in deriving reliable magnitude scaling relation for EWS and its limitations.

CONCLUSIONS

The magnitude scaling relation with τ_c parameter is introduced here for application in EWS. The relation is derived using 55 events recorded at RHUDRC stations in Alborz region where the Tehran city is located. In the contrary to the Taiwan and US, the distance among seismic stations in Iran is relatively large, which led to limited close in stations with 30 km epicentral distance (Wu and Kanamori, 2005b). This condition may largely reduce the number of data and reliability of the analysis results. Then, the epicentral distance of employed data is increased to the 90 km. This may led to magnitude estimation with a standard deviation of 0.6 unit of magnitude by introduced relation. This error could be decreased in a region with dense distribution of seismic stations or an increase in the number of stations in Tehran city.

In estimation of magnitude scaling relation, three choices of time window length for τ_c evaluation are examined. A time window with 3 sec length shows the best results with minimum standard deviation. The time windows with smaller and larger lengths than 3 sec increase the standard deviation and decrease early warning time, respectively. Furthermore, the seismicity and seismotectonic of Alborz region show very small probability of occurrence for earthquakes with magnitude larger than 7.5, which limit the application of time window with larger length than 3 sec.

To examine the reliability of the proposed relation, it compared with those developed by Wu and Kanamori (2005b) and Kanamori (2005) for a wide range of magnitude and Heidari et al. (2013) for a moderate magnitude range. A relatively good agreement among the results used to validate the developed relation. Furthermore, it reveals that the Heidari et al. (2013) relation overestimate the magnitude and need to be further examined. Finally, it is found that the derived scaling relation could successfully estimate the earthquake magnitude, and reliably applied in early warning systems.

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