Empirical Equations for the Predicting Duration of Earthquake Ground Motion in Iranian Plateau

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SUMMARY:
Earthquake ground motion can be characterized by many different parameters, each of which reflects some particular feature of the shaking such as the peak amplitudes, the frequency content, or the energy carried in the signal. A complete characterization of the ground motion must include a measure of its duration, or more specifically the duration of that part of the signal that is considered to be strong. This study presents new empirical predictive equations for significant duration of strong motion using the records from Iran Strong Motion Network (ISMN) which contains more than 3000 records with magnitude greater than 4.0. The equations proposed in this study can be used to estimate ground-motion durations from shallow crustal earthquakes of magnitude between Mw 4.0 and 7.5 at distances up to 150 km from the source.

Keywords: duration, strong motion, Iran, empirical relationships

1. GENERAL INSTRUCTIONS

Seismic design is primarily concerned with the balance between the potential of ground shaking to cause damage and the ability of structures to resist damage. For design purposes, the salient features of earthquake motions are quantified by engineering characteristic parameters. However, due to the complexity of the earthquake faulting process, seismic wave propagation, site response, etc., it is impossible to derive rigorous theoretical equations to predict ground motion characteristics. Thus, ground motion characteristic predictive relationships are typically developed from statistical analysis of earthquake motions. Accordingly, empirical predictive relationships play an essential role in estimating the engineering characteristics of ground motions from future earthquakes. Empirical predictive relationships should be periodically developed using up-to-date earthquake ground motion databases and robust regression techniques.

One of the important characteristic parameters of acceleration records is duration of strong motion. Strong ground motion duration is an important parameter for seismic risk assessment because it, along with the amplitude and frequency content of the ground motions, significantly influences the response of geotechnical and structural systems. When the non-linear behaviour of a system is considered, strong motion duration is a critical feature regarding the amount of potential damage. Hence, one important engineering parameter used in earthquake engineering is the strong ground motion duration.

Using the strong ground motion data set of Iran, this study develops empirical predictive relationships for Iran relating strong motion duration of earthquake horizontal ground motions to design earthquake parameters such as earthquake magnitude, site-to-source distance, and local site conditions (i.e., rock vs. soil). In this study, the significant duration of strong motions is considered.

Iran Strong Motion Network (ISMN) has started its activities since 1973 and provides one of the richest strong motion databases for shallow crustal earthquakes. The database of this study consists of 3117 three component records corresponding to 2378 events with magnitude greater than 4.0 recorded from 1973 to 2009.

2. IRAN STRONG MOTION NETWORK AND DATABASE

Iran Strong Motion Network (ISMN) has started its activities since 1973 in the organizational framework of the planning organization. The first analogue accelerograph installed in September 1973. The first accelerogram recorded (24 Feb 1973) in Jahrom city in Fars province (South Iran). In 1981 the strong motion network was transferred to Building and Housing Research Center (BHRC) and a new stage of its activities was corresponding born. The network is started its operation in 1973 and since then gradually extended. From 1973 to 1992 the network consisted of 274 analogue accelerographs (SMA1), with 1067 accelerograms.

At the present time the network consists (in operation) of 1093 digital (SSA2) accelerographs, 52 digital (CMG-5TD) Accelerographs and 2 analogue accelerographs. Most of the accelerograph units are concentrated in seismically active or in densely populated and industrialized areas. Since the installation of the first station, our strong motion network has recorded more than 7000 accelerograms.

2.1. Processing of Strong Ground Motions of Iran

Because of the large number of uncorrected records in the Iranian strong motion databank, an automatic correction procedure was implemented for correction of all records. In this procedure, all records have been filtered in time domain using 4th order Butterworth filter. The filter function has been implemented in forward and backward directions to ensure linear phase response of filter function. No baseline correction is applied to the records because of the use of high-pass filters in correction procedure.

The steps of correction procedure can be summarized as follow:

Analogue records

- Linear trend has been removed from the record.
- All analog records have been band-pass filtered between 0.2 to 20Hz.

Digital records

- Linear trend has been removed from the record.
- If the length of the pre-event was more than 5 seconds, it was considered as representative of noise and corresponding signal to noise ratio (S/N) was calculated.
- The cut-off frequencies of the filter were determined as the frequencies where H/V is more than 3.0. The limiting frequencies were 0.2 and 15 Hz for high-pass and low-pass cut-offs respectively. The lower limit of 0.05Hz was also applied for high-pass cut-off.
- If the length of the pre-event was less than 5.0 seconds, the default values of 0.1 and 30Hz were used as high-pass and low-pass cut-offs respectively.

In Figure 2.1, magnitude-distance distribution of selected strong motion records is presented. As it is clear from this figure, below distance of 1.0 kilometre, there are very few records in the database. However, strong motion database of Iran is very reach and contains records for different events with magnitude up to 7.5. Such rich database provides a concrete basis for any statistical analysis such as derivation of different ground motion prediction equations.

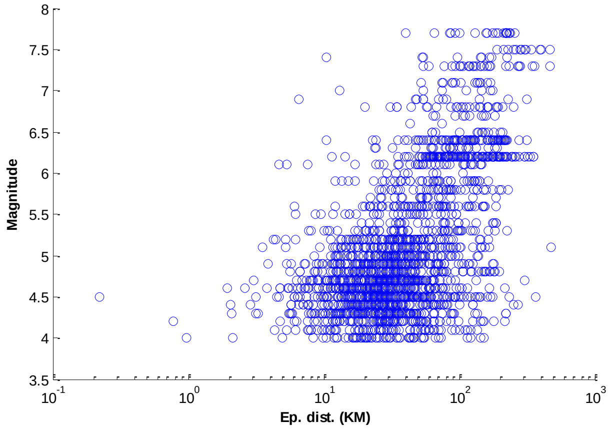

Figure 2.1. Magnitude of selected events versus epicentral distance of corresponding

3. DURATION OF STRONG MOTION

Duration, amplitude and frequency content of the ground motions,significantly influences the response of geotechnical and structural systems. Among these parameters, strong motion duration has an important position especially in non-linear dynamic analysis of systems.When the non-linear behavioursuch as degradation of stiffnessof a system is considered,strong motion duration is a critical feature regarding the amount of potential damage (e.g.,Bommer and Martinez-Pereira, 1999). In this vein, various definitions of strong motionduration have been proposed for quantifying the strong motion portion of earthquake ground shakings, which is the portion of the motion that is of engineering interest.

Of the numerous definitions of strong motion duration, significant durations (D_{5_75} andD_{5_95}) and bracketed duration ($D_{bracket}$) are most commonly used in engineering practice.Their definitions are based on either relative or absolute criterion. In this regard, Bommerand Martinez-Pereira (1999) proposed effective duration (D_{eff}) as an attempt to combinethe two criteria. In this study, accordingly, significant durationsis considered herein for developing duration relations. Also, note that this study only considers horizontal components of ground motions.

Significant duration is one of the most frequently used definitions by engineeringseismologists and earthquake engineers. The normalized cumulative squared acceleration, H(t), is used in its definition:

$$H(t) = \frac{\int_0^t a^2(t)dt}{\int_0^{t_d} a^2(t)dt} \tag{3.1}$$

Where $a(t)$ is the acceleration time history, and t_d is the total duration of the acceleration time history. Significant duration is most often definedas the time interval between H(t) = 5% and 75% (Somerville et al., 1997), or H(t) = 5%and 95% (Trifunac and Brady, 1975), denoted as D_{5_75} and $D_{5\text{-}95}$, respectively. The significant duration is useful because it reasonably represents the most significant portionof ground motions in terms of time.Figure 3.1 illustrates the determination of the significant durations D_{5_75} and D_{5_95} for an example acceleration time history using the $H(t)$ plot, known as the Husid plot (Husid, 1969).

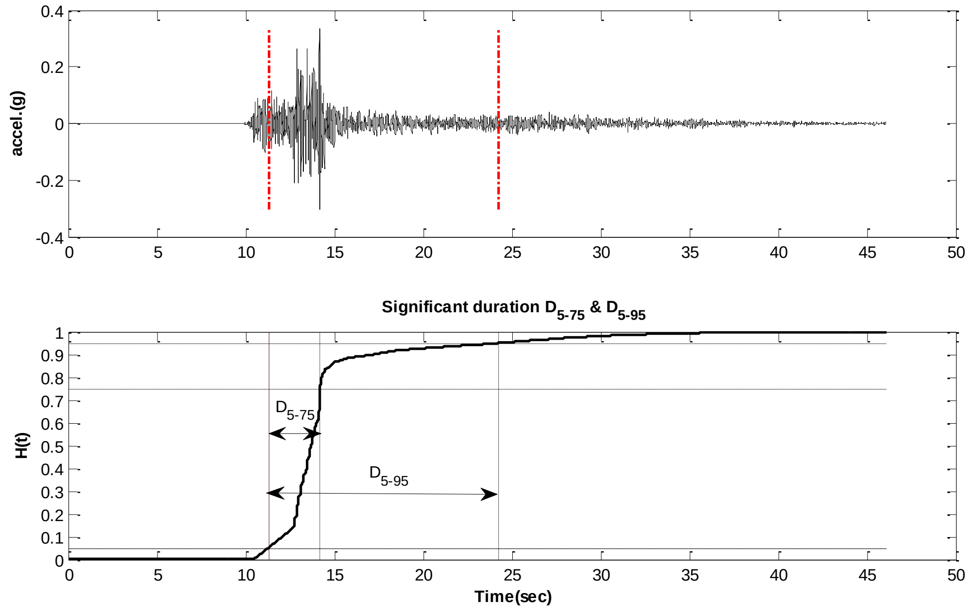

Figure 3.1 Significant duration of strong motion (top) obtained by using Husid plot (bottom)

4. FUNCTIONAL FORM AND PROPOSED MODEL

The functional form of the predictive relationship was obtained by modifying the modeldeveloped by Abrahamson and Silva (1996).In this study, linear relationships werefound to be the best functional form for site-to-source distance dependence,local site effects, and magnitude and site-to-source dependences coupled with local siteeffects. The resulting function form of the predictive relationship forsignificant durations of horizontal ground motions proposed in this study is

$$\ln D_{5-75} = \ln\{ C_1 + C_2 \exp(M - 6) + C_3 R + [S_1 + S_2(M - 6) + S_3 R] S_s\} \tag{4.1}$$

where C_1 through C_3 and S_1 through S_3 are regression coefficients; M is the momentmagnitude; R is the closest distance to the fault rupture plane (km); and Ss is a binary number representing local site conditions: Ss = 0 for rock sites and Ss = 1 for soil sites.

4.1 Regression Analysis and Results

In this study, linear regression analysis is used for obtaining different parameters of Eqn. 4.1. The regression analysis is performed for significant duration of D_{5_75}. For comparison of the results, the obtained regression models have been compared with the results of Lee 2009 that drive similar relationships for Western US (WUS) and central/eastern US(CEUS). From seismotectonic point of view, the Iranian Plateau is more similar to western US, thus, the results obtained in this study are compared to that of WUS. In Table 4.1, the parameter values of Eqn. 4.1 have been presented for Iraninan Plateau and WUS.

Table 4.1. Regression parameters for Iranian database and WUS

	c_1	c_2	c_3	s_1	s_2	s_3
D_{5-75}(WUS)	0	1.86	0.06	0.22	0	0
D_{5-75}(This study)	0	5.28	0.03	1.99	0	0

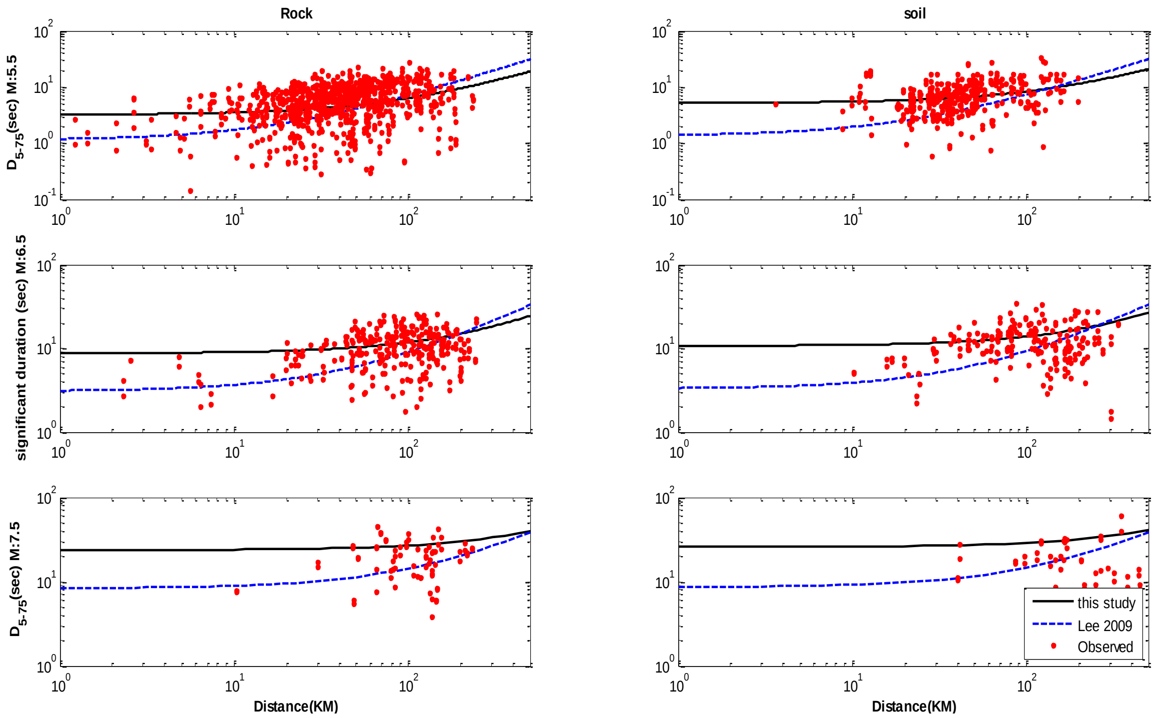

Figure 4.1 Comparison between regression curves of significant duration of this study and Lee 2009

In Figure 4.1, the regressing results of this study and Lee 2009 are presented for three magnitude values and two site conditions of rock and soil. As it is clear from this figure, the general trend of regression curves indicates that significant durations of Iranian strong motion records are less than WUS values. In the case of rock sites with event magnitude of 5.5 which there are a large number of data, the difference between two models is less than other cases. However in the cases of magnitude 7.5 events, the sporadic nature of available data could be the reason of great difference between two models. Figure 4.1 also turns out the increasing behaviour of significant duration with distance, however, this behaviour is much pronounced in WUS curves for distances more than 100 kilometres.

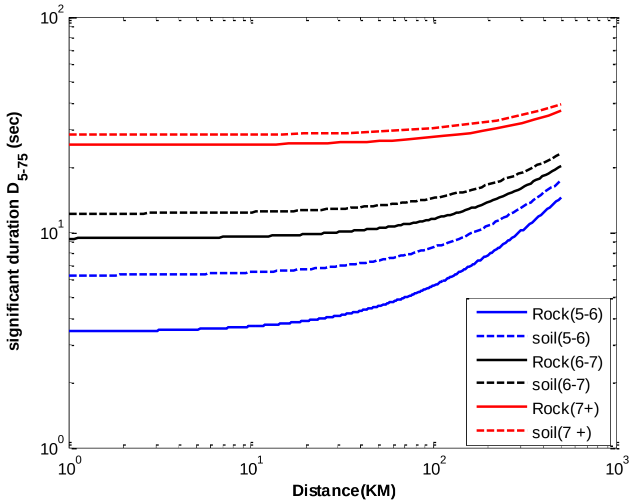

Figure 4.2 Comparison between significant duration prediction equations for different soil types and magnitude values

The effect of site soil conditions versus distance and magnitude is better depicted in Figure 4.2. With regard to this figure, the effect of soil stiffness is more noticeable for small magnitudes. However, by increasing distance, the difference between soil and rock curves reduces. In all cases, as it would be expected, the duration of strong motion in soil sites is larger the corresponding value for rock sites.

5. CONCLUSION

This article has presented new equations for the predictionof significant duration of strong motion time records, applicable to sites at up to 150 km from shallow crustal earthquakesof magnitude from Mw 4.0 to 7.5. The models arebased on simple functional forms and include only a small number of explanatory variables. This relationship was developed using the strong motion time histories recorded by Iranian Strong Motion Network. In the proposed equation, the effect of site conditions is also taken into account for developing relationship for rock and soil sites.

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