



## CHARACTERISTIC PERIOD INTERVAL OF SEISMIC GROUND MOTIONS

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### ***Abstract***

A characteristic period interval is defined on the basis of the frequency band of energy concentration to characterize the spectral properties of both the narrow-band and wide-band earthquake ground motions. A scale factor  $\eta$ , which describes the proportion of energy in frequency band of energy concentration and the total energy is stressed. The influence of  $\eta$  on the defined characteristic period interval is analyzed. The value of  $\eta$  is set as 85% according to the analysis results of a large number of earthquake ground motion records. In order to illustrate the advantage of the proposed characteristic period interval, three single characteristic periods are calculated and compared with the proposed interval. It reveals that the proposed characteristic period interval shows a good performance both in characterizing the narrow-band and wide-band ground motions.

The characteristic period interval is then derived based on the frequency band of energy concentration.

*Keywords: response spectrum, characteristic period interval, energy distribution*



## 1. Introduction

The spectral properties of earthquake ground motions plays an important role in the dynamic analysis and integrated design of seismic structures. When the main frequency component of an earthquake ground motion approximates to the primary period of the structure, the structural dynamic response arises and significant structural damages may occur [1,2]. The response spectrum as a means of describing the spectral properties of ground motions and its effects on structures have long been recognized by engineers and seismologists [3,4]. Characteristic period describing the spectral properties of the ground motion to a certain degree is one of the most important parameters of the design response spectrum. It is recognized that various characteristic periods, which are usually single scalar parameters, were used to characterize the frequency content of strong ground motion before [5-10]. While single scalar parameters were proved to be useful for the narrow-band ground motions, but remained challenges in efficiently characterizing the wide-band ground motions. Recently, the concept of frequency band of energy concentration [11] makes it possible to definite a double-parameter characteristic period.

In this study, a double-parameter characteristic period interval is proposed. The frequency band of energy concentration is used to define the characteristic period interval. The influence of a scale factor using in the definition of the frequency band on the proposed characteristic period interval is analyzed. To illustrate the advantage of the proposed double-parameter periods, the characteristic period interval and single characteristic periods are compared.

## 2. The characteristic period interval

### 2.1 Definition of the characteristic period interval

The characteristic period interval of earthquake ground motion record is defined based on the frequency band of energy concentration [11]. The energy spectrum density  $\Phi(f)$  of the acceleration time history  $a(t)$  is

$$\Phi(f) = \left| \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} a(t) e^{-i2\pi ft} dt \right|^2 = \frac{|F(f)|^2}{2\pi} \quad (1)$$

where  $F(f)$  denotes the Fourier spectrum of  $a(t)$ . The discrete energy spectrum density is written as

$$\Phi(f_k) = \frac{F^2(f_k)}{2\pi} \quad (2)$$

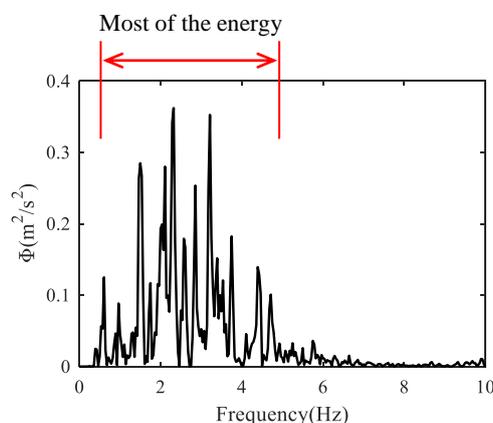


Fig. 1 Energy concentration shown on energy spectrum



As shown in Fig.1, the energy of earthquake ground motion mainly concentrates on a certain frequency band; see the frequency band between the two red vertical lines. The frequency band of energy concentration is then defined. Supposing the frequency domain of a discrete acceleration time history being  $[0, f_N]$ , a frequency band is chosen to satisfy the following formula

$$\sum_{i=m}^n \Phi(f_i) \cdot \Delta f = \eta \sum_{i=1}^N \Phi(f_i) \cdot \Delta f \quad (3)$$

where  $\eta$  is a scale factor between the energy in frequency band  $[f_m, f_n]$  and the total energy. One might realize that the boundary frequencies  $f_m$  and  $f_n$  are not unique satisfying a certain  $\eta$ . In order to bypass this issue, a constraint is used as follows

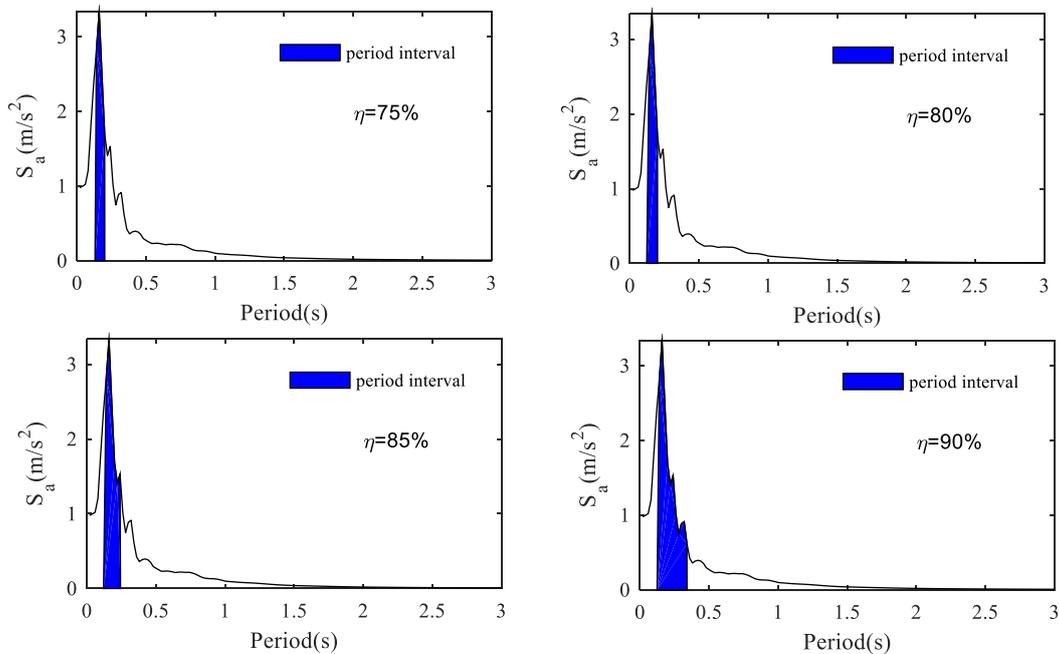
$$|f_n - f_m| \rightarrow \min \quad (4)$$

It is thus indicated that the shortest one in all the frequency bands satisfying Eq. (3) is the frequency band of energy concentration. Then the characteristic period interval  $[T_p, T_q]$  is defined as the inverse of the frequency band

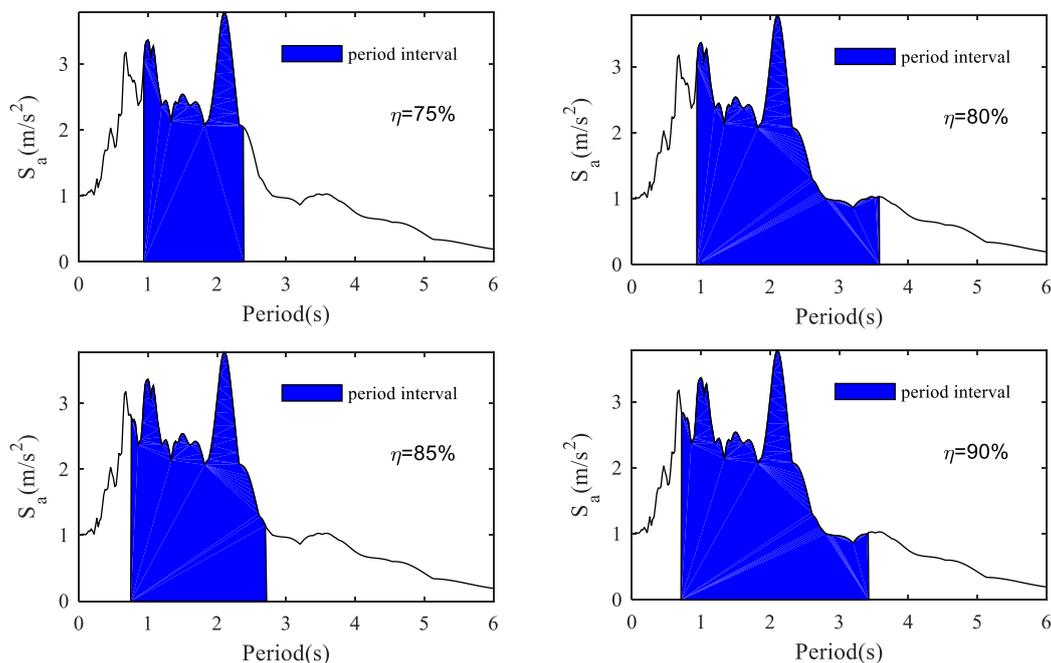
$$T_p = \frac{1}{f_n}; T_q = \frac{1}{f_m} \quad (5)$$

## 2.2 Scale factor

Obviously, the characteristic period interval is related to the scale factor  $\eta$ . The value of  $\eta$  is determined by trial. Two typical earthquake ground motion records are chosen to calculate the characteristic period interval when  $\eta$  equals 75%, 80%, 85%, 90%, respectively. The two chosen ground motions are narrow-band ground motion and wide-band ground motion, respectively. The results are shown in Fig.2.



(a) Narrow-band ground motion (1975-0607; Earthquake name: Northern Calif-07; Station: Cape Mendocino, 180)



(b) Wide-band ground motion (2007-0716; Earthquake name: Chuetsu-oki Japan; Station: KNG013; NS component)

Fig. 2 Characteristic period intervals calculated using different  $\eta$  ( $S_a$  is the spectral accelerations under damping ratio 5%)

As shown in Fig. 2,  $\eta$  has a critical influence on the characteristic period interval. Small  $\eta$  will result in a small period interval which is not enough to describe the spectral properties of earthquake ground motions, as shown in Fig.2 when  $\eta = 0.75$ . On the other side, large  $\eta$  will result in a much larger period interval which makes less sense to the spectral properties of the earthquake ground motions, as shown in Fig. 2 when  $\eta = 0.90$ . A large number of earthquake ground motion records are analyzed in the same way. Then a scale factor  $\eta = 0.85$  is used in order to secure the spectral properties in a trade-off sense. It is seen that the two parameters describe not only the energy concentration of earthquake ground motion but also the spectral properties.

Since the characteristic period interval describes the spectral properties of the earthquake ground motions, it could be used in grouping earthquake ground motion records according to the spectral properties. As shown in reference [11], 7692 earthquake ground motion records are grouped into 12 groups according to the site type and the frequency-band of energy concentration which is exactly similar to the characteristic period defined in this study. Grouping of earthquake ground motion records based on the characteristic period interval remains further study.

### 3. Comparison of the characteristic period interval and single characteristic periods

Three single characteristic periods are calculated and compared with the proposed period interval refers to paper [11]. The earthquake ground motions used in Section 2 are utilized again. The three single characteristic periods are typically chosen as the predominant spectral period  $T_p$ , the characteristic period  $T_g$ , and the smoothed spectral predominant period  $T_0$ . Predominant spectral period  $T_p$  is defined as the corresponding period of the maximum spectral acceleration under damping ratio 5% [7]. The characteristic period  $T_g$  [12,13] is defined as follows



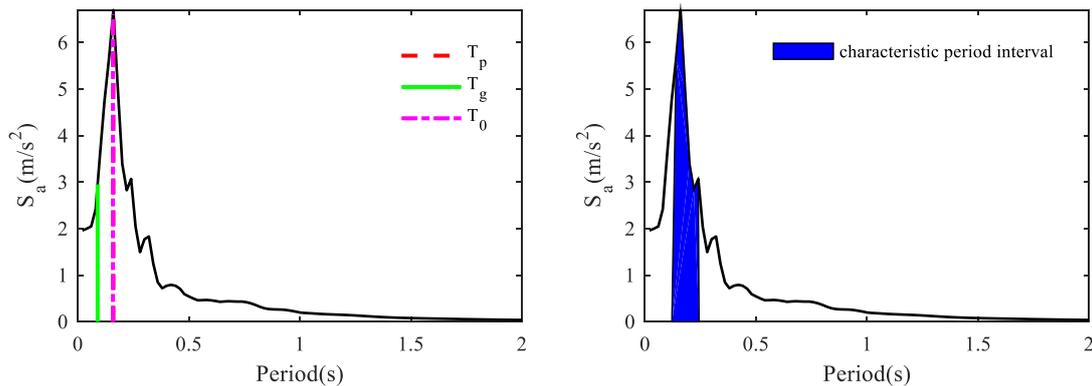
$$T_g = 2\pi \frac{EPV}{EPA} \quad (6)$$

where  $EPA$  (Effective Peak Acceleration) and  $EPV$  (Effective Peak Velocity) are the average ordinates of the acceleration and velocity response spectrum under damping ratio 5% in the selected period bands, i.e. 0.1-0.5 seconds for  $EPA$  and 0.8-1.2 seconds for  $EPV$ . The smoothed spectral predominant period  $T_0$ , proposed by Rathje et al. [7]

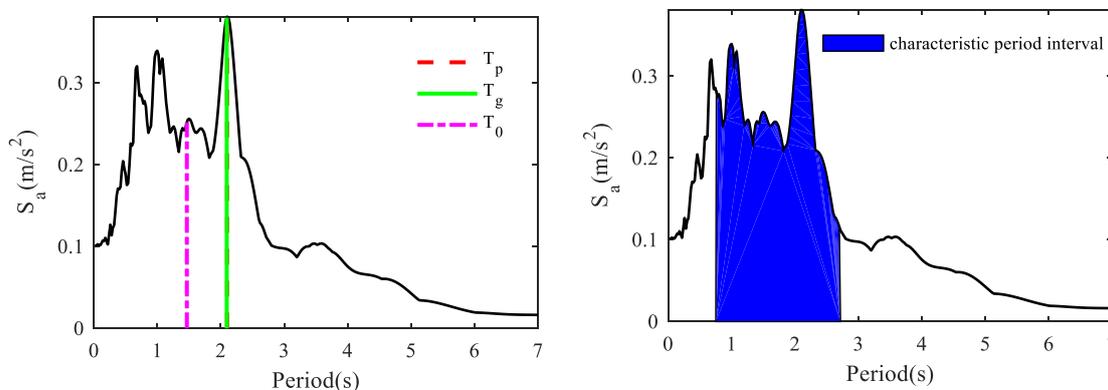
$$T_0 = \frac{\sum_i T_i \times \ln\left(\frac{S_a(T_i)}{PGA}\right)^2}{\sum_i \ln\left(\frac{S_a(T_i)}{PGA}\right)^2} \quad \text{for } T_i \text{ with } \frac{S_a}{PGA} \geq 1.2 \quad (7)$$

where  $S_a(T_i)$  are the spectral accelerations under damping ratio 5% corresponding to discrete periods  $T_i$ , and  $PGA$  is peak ground acceleration.

As shown in Figure 3 and Table 1, single parameters  $T_p$ ,  $T_g$ ,  $T_0$  have a better performance in characterizing the frequency content of the narrow-band ground motion than the wide-range ground motion. However, the frequency band of energy concentration behaves well in characterizing both the narrow-band and the wide-band ground motions.



(a) Narrow-band ground motion (1975-0607; Earthquake name: Northern Calif-07; Station: Cape Mendocino, 180)



(b) Wide-band ground motion (2007-0716; Earthquake name: Chuetsu-oki Japan; Station: KNG013; NS component)

Fig. 3 Comparison of single periods and characteristic period interval



Table 1 – Values of periods characterizing frequency content of earthquake ground motion

Type of ground motion	Single scalar parameter / (s)			Period band
	$T_p$	$T_g$	$T_0$	
Narrow-band	0.10	0.09	0.16	0.12-0.24
Wide-band	2.10	2.10	1.47	0.75-2.72

#### 4. Conclusions

The characteristic period interval is defined according to the frequency band of energy concentration. The comparison of the characteristic period interval and single characteristic periods shows that the proposed characteristic period interval shows a good performance both in characterizing the narrow-band and wide band ground motions. Furthermore, the proposed characteristic period interval could be used in the grouping of earthquake ground motion records and the ground motion selection.

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