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Quantitative bounded method of special long-period ground motions

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Abstract. The resonance effect of special long-period ground motions to (super) high-rise buildings is significant, which is likely to cause serious damage to these long-period structures. Therefore, the influence of long-period ground motions cannot be ignored in the seismic design of long-period structures. To provide theoretical basis and quantitative criteria for the selection and evaluation of long-period ground motion records, a quantitative bounded method based on the normalized acceleration spectra is proposed. Firstly, two types of long-period ground motions with reliable information are selected for this research, and the baseline drifting on acceleration, velocity and displacement time-history curve are corrected. Then, the Fourier amplitude spectrum and Power spectral density amplitude of special long-period ground motions are analyzed. Lastly, a quantitative boundary parameter to distinguish near-fault pulse-like (NFPL) and far-field harmonic (FFH) ground motions from common ground motions are discussed. Study results are obtained as follows: The frequency distribution of special long-period ground motions is relatively concentrated in low-frequency band, and the frequency distribution of common ground motions is relatively dispersed in medium-high-frequency band. Power spectral density amplitude and Fourier amplitude spectrum are the specific performance of energy distribution about earthquake records from the aspect of frequency domain, and they have no interrelation with structural seismic response under earthquake excitation. The specific earthquake records whose weighted average value of acceleration amplification factor is less than 0.2 are known as common ground motions. The specific earthquake records whose weighted average value is between in 0.2~0.6 are known as NFPL ground motions. The specific earthquake records whose weighted average value is beyond 0.6 are known as FFH ground motions. It would provide reference for the selection of long-period ground motions during seismic analysis of long-period such as super high-rise building structures.

1. Introduction

In the recorded strong earthquake data, there are two types of special earthquake records that are considered to be long-period ground motions. One is near-fault pulse-like (NFPL) ground motions, and the other is far-field harmonic (FFH) ground motions. Studies have shown that these two types of special ground motions exhibit significant long-period (low-frequency) properties, so they can be called long-period ground motions [1–5]. Nowadays, with the rapid development of economic construction, long-period such as (super) high-rise structures have been widely built in major cities. Multiple earthquake damages indicate that long-period ground motions have a magnifying effect on long-period structures, and they are prone to severe destroy to long-period structures [6–12].

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Cheng et al. [13], who studied the basic characteristic parameters and influencing factors of long-period ground motion records, thought near-fault earthquake has high amplitude intensity and short strong-shock duration, and far-field earthquake has small peaks of acceleration, velocity, displacement time history and long strong-shock duration. Dong et al. [14], who analyzed the spectral characteristics and intensity indices for near-fault ground motions, suggested the peak ground velocity (PGV) index can be employed for medium-to-long period structures. Wang et al. [15] selected reasonable intensity indices as the input of structural seismic design under two types of long-period ground motions. Shih et al. [16] evaluated the relationship between groundwater and ground motions quantitatively in the frequency domain, and the spectral analysis becomes feasible to assess the effect of the groundwater level on the separation of FFH and NFPL movements. Zhao et al. [17] investigated the low-frequency characterizations of pulse-type ground motions through ground motion components instead of original records, and the ground motion components are obtained by a decomposed method based on multi-resolution analysis. Li et al. [18] proposed classification method for long period ground motions based on component decomposition with Hilbert-Huang transform. Shao et al. [19] researched the method to definite the long-period ground motion based on EMD with elastic spectrum.

Data analysis on strong earthquake records is an important part of earthquake engineering, and it is also the research foundation of various seismic engineering topics. At present, there are a small amount of research results on how to judge and select long-period ground motions, and they are mainly limited to qualitative analysis. However, response spectrum theory is an important tool to describe the relationship between earthquake excitation and structural response in the field of earthquake engineering and seismic design [20–22]. Response spectra become the focus of structural dynamic analysis and seismic design because it can directly show the maximum response of single degree of freedom (SDOF) system under earthquake action [23]. Therefore, it is necessary to quantify the definition of common ground motions and two types of special long-period ground motions from the perspective of response spectra.

Firstly, typical 189 long-period and 26 common earthquake records with reliable information are selected from Pacific Earthquake Engineering Research Center (PEER) and National Research Institute for Earth Science and Disaster Resilience (NIED). The types of Polynomial Linear and High-pass Filtering Butterworth are employed to correct the baseline of original earthquake records. Then, the Fourier amplitude spectrum and Power spectral density amplitude of ground motions are analyzed from the aspect of frequency domain. On the basic of normalized acceleration spectra, the boundary parameter distinguishing long-period ground motions from common ground motions is defined, and a quantitative evaluation index is proposed by calculating and analyzing the boundary parameters about a large number of NFPL and FFH ground motions. The quantitative boundary parameter would provide theoretical basis and quantitative criteria for the selection and evaluation of long-period earthquake records during seismic response analysis for high-rise building structures.

2. Methods

2.1. Selection of long-period ground motion records

Based on the property of long-period ground motions and selection principle of seismic waves [24–26], the earthquake records whose frequency distribution of Fourier amplitude spectrum are almost within 0.1~1.0 Hz are considered as long-period ground motions. 89 NFPL and 100 FFH ground motion records are selected from PEER and NIED. To deeply study the characteristic of long-period ground motions, 26 common ground motions are selected for a comparative analysis. The criteria of US NEHRP classification is adopted to calculate the site category of selected ground motions, and all earthquake records are classified as different site classifications. Tables 1–3 demonstrate the basic information of NFPL, FFH and common ground motion records, respectively.

Table 1. Basic information of NFPL ground motion records.

station /component	M_w	rupture distance	site class	station /component	M_w	rupture distance	site class	station /component	M_w	rupture distance	site class
1085_SCE018	6.7	5.2	C	953_MUL009	6.7	17.1	D	TCU116-NS	7.6	12.38	C
1085_SCE288	6.7	5.2	C	953_MUL279	6.7	17.1	D	CHY035-EW	7.6	12.65	C
1084_SCS052	6.7	5.3	D	1016_NYA090	6.7	18.5	C	CHY035-NS	7.6	12.65	C
1084_SCS142	6.7	5.3	D	1016_NYA180	6.7	18.5	C	TCU104-EW	7.6	12.87	C
1086_SYL090	6.7	5.3	C	1012_LA0000	6.7	19.1	C	TCU104-NS	7.6	12.87	C

station /component	M_w	rupture distance	site class	station /component	M_w	rupture distance	site class	station /component	M_w	rupture distance	site class
1086_SYL360	6.7	5.3	C	1012_LA0090	6.7	19.1	C	TCU109-EW	7.6	13.06	C
1045_WPI046	6.7	5.5	D	TCU068-EW	7.6	0.32	C	TCU109-NS	7.6	13.06	C
1045_WPI316	6.7	5.5	D	TCU068-NS	7.6	0.32	C	TCU128-EW	7.6	13.13	C
1013_LDM064	6.7	5.9	C	TCU065-EW	7.6	0.57	D	TCU128-NS	7.6	13.13	C
1013_LDM334	6.7	5.9	C	TCU065-NS	7.6	0.57	D	TCU074-EW	7.6	13.46	C
1044_NWH090	6.7	5.9	D	TCU052-EW	7.6	0.66	C	TCU074-NS	7.6	13.46	C
1044_NWH360	6.7	5.9	D	TCU052-NS	7.6	0.66	C	TCU048-EW	7.6	13.53	C
1063_RRS228	6.7	6.5	D	TCU102-EW	7.6	1.49	C	TCU048-NS	7.6	13.53	C
1063_RRS318	6.7	6.5	D	TCU102-NS	7.6	1.49	C	CHY034-EW	7.6	14.82	C
1050_PAC175	6.7	7	A	CHY080-EW	7.6	2.69	C	CHY034-NS	7.6	14.82	C
1050_PAC265	6.7	7	A	CHY080-NS	7.6	2.69	C	TCU123-EW	7.6	14.91	D
1052_PKC090	6.7	7.6	C	TCU103-EW	7.6	6.08	C	TCU123-NS	7.6	14.91	D
1052_PKC360	6.7	7.6	C	TCU087-NS	7.6	6.98	C	TCU107-EW	7.6	15.99	C
949_ARL090	6.7	8.7	D	TCU120-EW	7.6	7.4	C	TCU107-NS	7.6	15.99	C
949_ARL360	6.7	8.7	D	TCU136-EW	7.6	8.27	C	TCU064-EW	7.6	16.59	C
1082_RO3000	6.7	10.1	D	TCU136-NS	7.6	8.27	C	TCU064-NS	7.6	16.59	C
1082_RO3090	6.7	10.1	D	CHY006-EW	7.6	9.76	C	CHY104-EW	7.6	18.02	D
960_LOS000	6.7	12.4	D	CHY006-NS	7.6	9.76	C	CHY104-NS	7.6	18.02	D
960_LOS270	6.7	12.4	D	TCU138-NS	7.6	9.78	C	CHY025-EW	7.6	19.07	D
1083_GLE170	6.7	13.3	C	TCU063-EW	7.6	9.78	C	CHY025-NS	7.6	19.07	D
1083_GLE260	6.7	13.3	C	TCU063-NS	7.6	9.78	C	TCU036-EW	7.6	19.83	C
1080_KAT000	6.7	13.4	C	CHY029-EW	7.6	10.96	C	TCU036-NS	7.6	19.83	C
1080_KAT090	6.7	13.4	C	CHY029-NS	7.6	10.96	C	TCU039-EW	7.6	19.89	C
1087_TAR090	6.7	15.6	D	TCU100-NS	7.6	11.37	C	TCU039-NS	7.6	19.89	C
1087_TAR360	6.7	15.6	D	TCU116-EW	7.6	12.38	C				

Table 2. Basic information of FFH ground motion records.

station /component	M_w	epicenter distance	site class	station /component	M_w	epicenter distance	site class	station /component	M_w	epicenter distance	site class
EHMH07-EW2	7.3	203	D	NGN024-EW	7.3	721	D	YMT002-EW	9.0	236	D
EHMH07-NS2	7.3	203	D	NGN024-NS	7.3	721	D	YMT002-NS	9.0	236	D
EHM016-EW	7.3	213	D	IUBH03-EW	8.0	206	E	YMTH12-EW2	9.0	256	C
EHM016-NS	7.3	213	D	IUBH03-NS	8.0	206	E	YMTH12-NS2	9.0	256	C
SMNH09-EW2	7.3	233	C	HKD130-EW	8.0	241	C	FKSH03-EW2	9.0	279	D
SMNH09-NS2	7.3	233	C	HKD130-NS	8.0	241	C	FKSH03-NS2	9.0	279	D
EHMH04-EW2	7.3	249	D	ABSH04-EW2	8.0	280	C	NIG009-EW	9.0	310	E

station /component	M_w	epicenter distance	site class	station /component	M_w	epicenter distance	site class	station /component	M_w	epicenter distance	site class
EHMH04-NS2	7.3	249	D	ABSH04-NS2	8.0	280	C	NIG009-NS	9.0	310	E
HRS004-EW	7.3	260	C	HKD151-EW	8.0	318	D	AOMH10-EW2	9.0	336	D
HRS004-NS	7.3	260	C	HKD151-NS	8.0	318	D	AOMH10-NS2	9.0	336	D
KOCH13-EW2	7.3	285	C	AOM018-EW	8.0	343	C	AOM019-EW	9.0	366	E
KOCH13-NS2	7.3	285	C	AOM018-NS	8.0	343	C	AOM019-NS	9.0	366	E
OKYH06-EW2	7.3	333	C	HKD025-EW	8.0	374	D	CHBH20-EW2	9.0	416	A
OKYH06-NS2	7.3	333	C	HKD025-NS	8.0	374	D	CHBH20-NS2	9.0	416	A
TKS005-EW	7.3	360	D	AKT013-EW	8.0	399	C	NIGH17-EW2	9.0	443	C
TKS005-NS	7.3	360	D	AKT013-NS	8.0	399	C	NIGH17-NS2	9.0	443	C
TTR006-EW	7.3	404	D	AKT018-EW	8.0	437	D	YMN010-EW	9.0	472	C
TTR006-NS	7.3	404	D	AKT018-NS	8.0	437	D	YMN010-NS	9.0	472	C
OSK010-EW	7.3	454	D	YMT001-EW	8.0	482	E	YMNH13-EW2	9.0	500	B
OSK010-NS	7.3	454	D	YMT001-NS	8.0	482	E	YMNH13-NS2	9.0	500	B
NAR007-EW	7.3	490	C	YMTH14-EW2	8.0	513	D	HKD102-EW	9.0	531	D
NAR007-NS	7.3	490	C	YMTH14-NS2	8.0	513	D	HKD102-NS	9.0	531	D
KYTH04-EW2	7.3	523	B	YMT015-EW	8.0	548	E	SZOH53-EW2	9.0	562	B
KYTH04-NS2	7.3	523	B	YMT015-NS	8.0	548	E	SZOH53-NS2	9.0	562	B
MIEH03-EW2	7.3	557	C	FKS020-EW	8.0	580	E	AIC005-EW	9.0	599	D
MIEH03-NS2	7.3	557	C	FKS020-NS	8.0	580	E	AIC005-NS	9.0	599	D
MIEH07-EW2	7.3	587	C	FKSH21-EW2	8.0	640	C	AIC003-EW	9.0	636	E
MIEH07-NS2	7.3	587	C	FKSH21-NS2	8.0	640	C	AIC003-NS	9.0	636	E
AIC001-EW	7.3	620	E	NIGH11-EW2	8.0	687	C	HKD030-EW	9.0	676	D
AIC001-NS	7.3	620	E	NIGH11-NS2	8.0	687	C	HKD030-NS	9.0	676	D
AIC015-EW	7.3	654	D	NGNH28-EW2	8.0	763	B	ABSH01-EW2	9.0	714	B
AIC015-NS	7.3	654	D	NGNH28-NS2	8.0	763	B	ABSH01-NS2	9.0	714	B
GIFH24-EW2	7.3	683	B	MYG005-EW	9.0	208	D				
GIFH24-NS2	7.3	683	B	MYG005-NS	9.0	208	D				

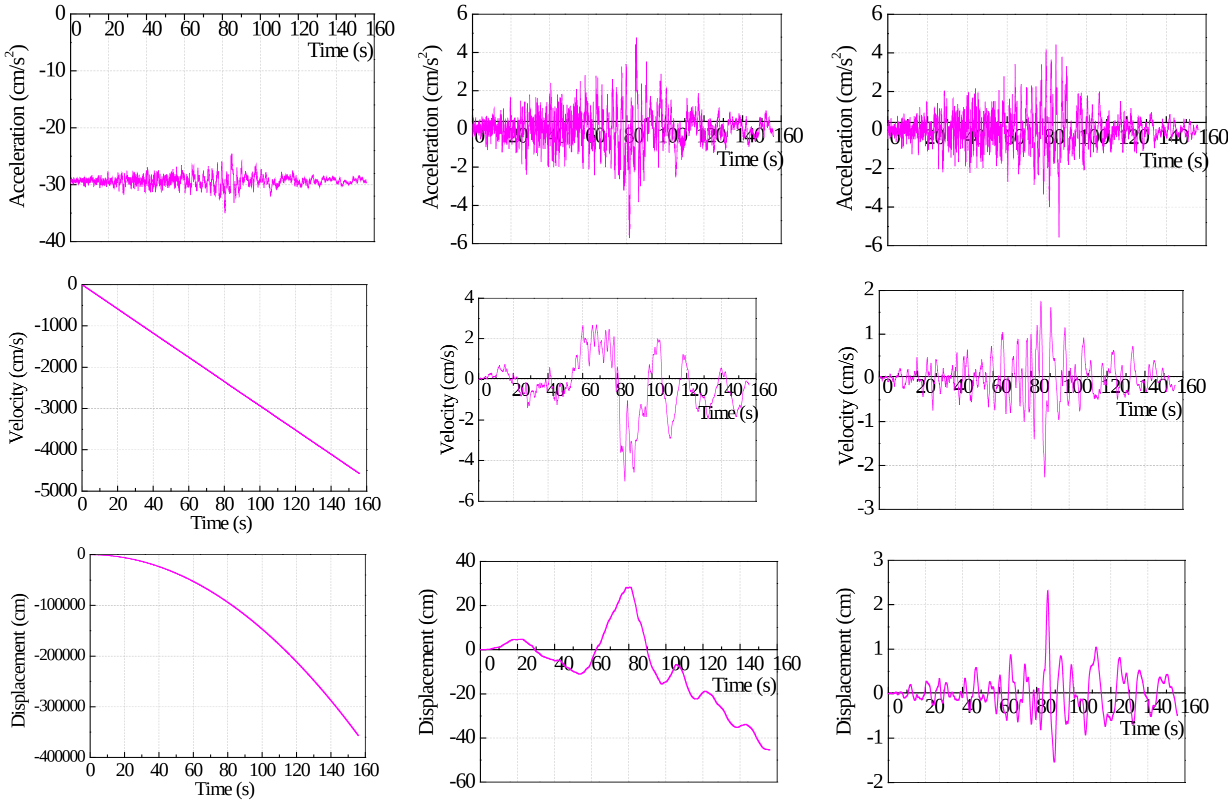
Table 3. Basic information of common ground motion records.

station /componen	M_w	rupture distanc	site clas	station /componen	M_w	rupture distanc	site clas	station /componen	M_w	rupture distanc	site clas
ELC000	5.0	34.98	D	TAF111	7.3	38.89	C	HCH090	6.9	27.6	D
ELC090	5.0	34.98	D	PAS180	7.3	125.59	C	HCH180	6.9	27.6	D
ELC180	6.5	6.09	D	PAS270	7.3	125.59	C	B-ICC000	6.5	18.2	D
ELC270	6.5	6.09	D	OSA000	6.9	21.35	D	B-ICC090	6.5	18.2	D
OKA000	6.9	86.94	C	OSA090	6.9	21.35	D	B-	6.5	13.03	D
OKA090	6.9	86.94	C	SHI000	6.9	19.15	D	B-	6.5	13.03	D
TAB-L1	7.3	2.05	B	SHI090	6.9	19.15	D	B-IVW090	6.5	23.85	E
TAB-T1	7.3	2.05	B	AGW000	6.9	24.57	D	B-IVW360	6.5	23.85	E
TAF021	7.3	38.89	C	AGW090	6.9	24.57	D				

2.2. Processing of long-period ground motion records

Earthquake records obtained from seismic stations not only contain ground vibration information purely caused by earthquake itself, but also much complex interference such as background noise and instrumental errors. And the long-period components of these interferences drift the baseline of time-history curve about earthquake records. This phenomenon of baseline drifting has no significant impact on acceleration time-history (the error of acceleration peak is not beyond 3 %). However, the baseline drifting would be gradually accumulated with the numerical integration of acceleration and it eventually results in a great distortion of velocity and displacement time-history curve. To remove the influence on time-history curve by some non-seismic factors, the baseline of time-history curve about earthquake records should be corrected before they are used for further study.

Polynomial Linear is applied to adjust the baseline, and High-pass Filtering Butterworth is employed to correct the existed baseline drifting of original earthquake records. The low-frequency components of earthquake records are considered as much as possible to be retained during the filtering correction process. Taking as an example of a FFH ground motion record of AIC005-EW, Fig. 1a illustrates a time-history curve of original ground motions, Fig.1 b–c illustrate time-history curves after baseline adjustment and high-pass filter.



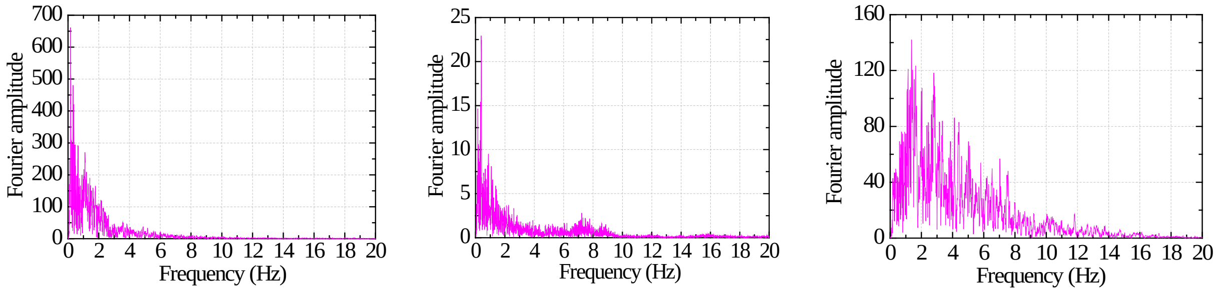
(a) original ground motion record **(b) after baseline adjustment** **(c) after high-pass filter**

Figure 1. Baseline correction of AIC005-EW.

2.3. Frequency content characteristics of long-period ground motions

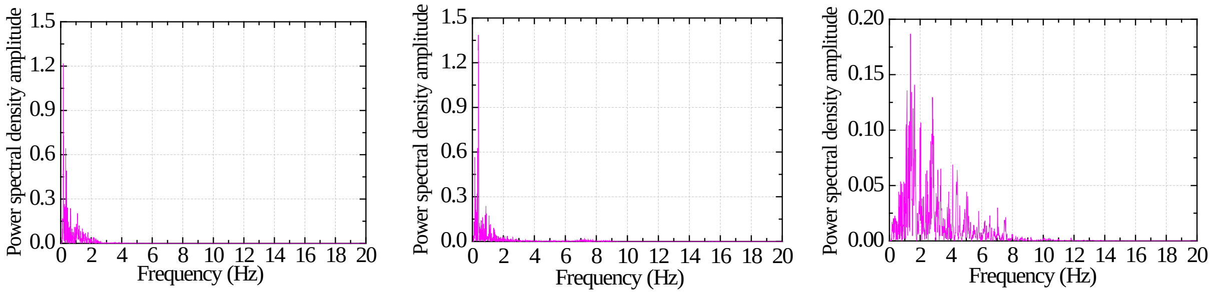
Some cases about structural seismic damage have been studied in recent years, and it is clear that the frequency content characteristic of ground motions has a significant impact on structural seismic response. If the predominant frequency of ground motions is within low-frequency band, it would cause a huge reaction on long-period structures. On the contrary, if the predominant frequency is within high-frequency band, it is more harmful to rigid structures. Therefore, the frequency characteristic is one of the most important aspects to reveal the basic property of ground motion records.

Fourier amplitude spectrum reflects the energy distribution of ground motions from the aspect of frequency domain, and it shows the energy carried by harmonic vibration at different frequency. Fourier amplitude spectrum, expressing what kinds of frequency components contained by ground motions, can clearly show amplitude content at each frequency component and maximum amplitude at a specific frequency component. Power spectral density amplitude, being defined as the mean square value of Fourier amplitude spectrum, is a physical quantity to describe stochastic process characteristic from the aspect of frequency domain. Power spectral density amplitude can also reflect the energy distribution of ground motion records along frequency axis.



(a) CHY104-EW **(b) AIC005-EW** **(c) TAF021**

Figure 2. Fourier amplitude spectrum.



(a) CHY104-EW **(b) AIC005-EW** **(c) TAF021**

Figure 3. Power spectral density amplitude.

Taking as examples of a NFPL ground motion of CHY104-EW, a FFH ground motion of AIC005-EW and a common ground motion of TAF021, Fig. 2–3 illustrate the Fourier amplitude spectrum and Power spectral density amplitude of ground motion records. The low-frequency components of CHY104-EW and AIC005-EW are very abundant. The energy distribution of CHY104-EW is mainly within 0.15~0.39 Hz, while the energy distribution of AIC005-EW is mainly within 0.15-0.42 Hz. It shows that the frequency distribution of long-period ground motion records is concentrated within relatively low-frequency band. The energy distribution of TAF021 is mainly within 1.07~2.84 Hz and it shows that the frequency distribution of common ground motions is concentrated within relatively high-frequency band. After a comparative analysis of Fig. 2 and Fig. 3, there is no essential difference between Power spectral density amplitude and Fourier amplitude spectrum, and both of them are the specific performance of energy distribution about earthquake records from the aspect of frequency domain. Power spectral density amplitude and Fourier amplitude spectrum are the physical properties of earthquake records themselves, and they have no interrelation with structural response under earthquake excitation.

2.4. Quantitative bounded method of long-period ground motions

Compared with common ground motions, long-period ground motions are characterized by abundant low-frequency components and long excellence period. In recent years, with the extensive study of long-period earthquakes, the definition about long-period ground motions is gradually developed from qualitative to semi-quantitative and quantitative. For example, the special earthquake records whose weighted average value of acceleration amplification factor within the period range of 2~10 s is larger than 0.4 can be bounded as the long-period ground motions [27], or the energy proportion of special earthquake records before 1 Hz can also be as the basis for defining long-period ground motions [28], and so on.

Fig. 4 demonstrates the comparison on normalized acceleration spectra (also known as magnification factor spectra) under three types of earthquake action. Acceleration amplitude is scaled to 1 cm/s^2 for calculating the normalized acceleration spectra of ground motions. Normalized acceleration spectra can eliminate the influence on the ordinate value of response spectra by earthquake intensity, and it also can reflect the response amplification of SDOF system under earthquake excitation. With reference to Fig. 4, it shows that the acceleration amplification factor of NFPL and FFH ground motions is larger than that of common ground motions in the period range of beyond 2 s. If the low-frequency components of earthquake records is much rich, it would bring more serious damage on long-period structures. Therefore, the boundary parameter combining the earthquake characteristic and structural seismic response could have a certain engineering significance.

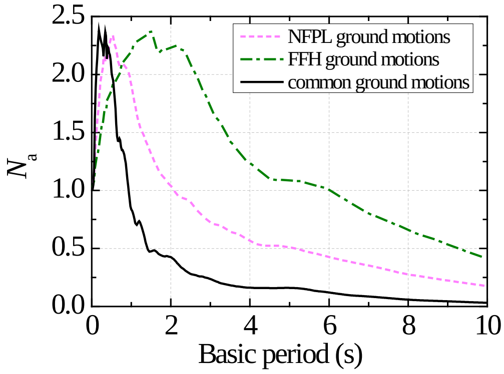


Figure 4. Normalized acceleration spectra.

According to equation (1), the weighted average value of acceleration amplification factor within the period range of 2~10s can be calculated.

$$\beta_l = \frac{\sum T_i^2 \left(\frac{S_a(T_i)}{PGA} \right)}{\sum T_i^2} \tag{1}$$

where, β_l is the weighted average value of spectra amplitude and the square of discrete period; T_i is the equidistant discrete period of acceleration response spectra with the damping ratio of 5 %, and T_i is within the period range of [2, 10]; $S_a(T_i)$ is the amplitude value of acceleration response spectra corresponding to T_i; PGA is the peak of acceleration time history.

3. Results and Discussion

Table 4. Means, standard deviations and variation coefficients of weighted average value.

types of earthquake records	site class	weighted average value		
		mean	standard deviation	variation coefficient (%)
NFPL ground motions	C	0.388	0.0121	3.12
	D	0.325	0.0167	5.14
FFH ground motions	C	0.935	0.0223	2.39
	D	0.717	0.0356	4.97
	E	0.688	0.0274	3.98
common ground motions	C	0.077	0.0019	2.47
	D	0.051	0.0017	3.33

Table 4 demonstrates the means, standard deviations and variation coefficients about the weighted average value of acceleration amplification factor in various site classifications. The weighted average value under common ground motions is the smallest, NFPL ground motions is the second and FFH ground motions is the largest. On the whole, the means of the weighted average value under long-period ground motions are obviously larger than that under common ground motions. Therefore, the weighted average value can be considered as the quantitative bounded parameter to distinguish long-period ground motions from common ground motions. The variation coefficients in the D site classification is larger than that in the C site classification, which shows that the weighted average value in the D site classification is more discretized. Note that the statistical weighted average value of acceleration amplification factor in the same site classification would have a certain deviation. This is because the interaction between focal mechanism, earthquake magnitude, site-to-soil distance, propagation medium and path are not taken into account. At the same time, the calculated means are somewhat different when different strong-earthquake records are selected for statistical calculation. Therefore, the weighted average value of acceleration amplification factor can be determined based on the reliability requirements of structural seismic design in practical applications.

Table 5. Standard-deviation calculation of weighted average value.

types of earthquake records	site class	mean (μ)	standard deviation (σ)	μ-2σ	μ-σ	μ+σ	μ+2σ
NFPL ground motions	C	0.388	0.0121	0.3638	0.3759	0.4001	0.4122
	D	0.325	0.0167	0.2916	0.3083	0.3417	0.3584
FFH ground motions	C	0.935	0.0223	0.8904	0.9127	0.9573	0.9796
	D	0.717	0.0356	0.6458	0.6814	0.7526	0.7882
	E	0.688	0.0274	0.6332	0.6606	0.7154	0.7428
common ground motions	C	0.077	0.0019	0.0732	0.0751	0.0789	0.0808
	D	0.051	0.0017	0.0476	0.0493	0.0527	0.0544

Table 5 demonstrates the standard-deviation calculation of the weighted average value in various site classifications. The weighted average value of acceleration amplification factor from 2 s to 10 s can be regarded as a quantitative bounded parameter to distinguish long-period ground motions from common ground motions. According to the statistical results of 87 NFPL, 86 FFH and 24 common ground motion records, the specific earthquake records whose weighted average value of acceleration amplification factor is less than 0.2 with the dominant components of high-frequency and above are known as common ground motions. The specific earthquake records whose weighted average value is between in 0.2~0.6 with less high-frequency components and rich low-frequency components are known as NFPL ground motions. The specific earthquake records whose weighted average value is beyond 0.6 with the dominant components of low-frequency are known as FFH ground motions. Compared with NFPL ground motions, FFH ground motions have less high-frequency components. This is because that the high-frequency components are attenuated and low-frequency components are amplified by soft-soil site with the increase of propagation distance under FFH ground motions.

The Reference [26] drew a conclusion that, the ground motions are classified into long-period (β_l >0.4), moderate period (0.2 ≤ β_l ≤ 0.4) and short period (β_l < 0.2) ground motions[1]. Compared with these results, this study further divides long-period ground motions into NFPL and FFH ground motions. On this basis, the ground motions are classified into FFH (β_l > 0.6), NFPL (0.2 ≤ β_l ≤ 0.6) and common (β_l < 0.2) ground motions. This conclusion makes the classification of long-period ground motions more specific and close to the actual situation, and it also promotes the deep study of different mechanisms on structural damage caused by long-period ground motions.

The weighted average value of acceleration amplification factor from 2 s to 10 s is taken as a quantitative boundary parameter to distinguish NFPL and FFH ground motions from common ground motions, which would provide the theoretical basis and quantitative criteria for the selection and evaluation of long-period ground motion records during seismic response analysis for high-rise building structures.

4. Conclusion

Firstly, typical 189 long-period and 26 common ground motion records with reliable information are selected for this research. Then, the frequency content characteristics of long-period ground motion records are analyzed. Lastly, a quantitative boundary parameter to distinguish NFPL and FFH ground motions from common ground motions is proposed. The main conclusions are obtained as follows:

1. The frequency distribution of long-period ground motions is relatively concentrated in low-frequency band, and the frequency distribution of common ground motions is relatively dispersed in medium-high-frequency band. Power spectral density amplitude and Fourier amplitude spectrum are the specific performance of energy distribution about earthquake records from the aspect of frequency domain, and they have no interrelation with structural seismic response under earthquake excitation.

2. The specific earthquake records whose weighted average value of acceleration amplification factor is less than 0.2 are known as common ground motions. The specific earthquake records whose weighted average value is between in 0.2~0.6 are known as NFPL ground motions. The specific earthquake records whose weighted average value is beyond 0.6 are known as FFH ground motions.

[1] http://www.cq-vip.com/qk/92375x/201405/663002935.html

3. The high-frequency components of FFH ground motions is less than that of NFPL ground motions, because the high-frequency components are attenuated and low-frequency components are amplified by the soft-soil site under FFH ground motions. The quantitative boundary parameter would provide the theoretical basis and quantitative criteria for the selection and evaluation of long-period ground motion records during seismic response analysis for high-rise building structures.

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