STUDY ON THE METHOD OF DETERMINING SEISMIC DESIGN INPUTS BASED ON GROUND MOTIONS' POWER SPECTRUM

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Abstract

In recent years, the seismic design method based on energy has attracted much attention in the engineering field, and the method of determining seismic design inputs focusing on energy analysis, is still a long-term pending problem. In traditional seismic design method based on force, the inputs are usually selected according to the response spectrum, which is effective in controlling the seismic force acting on the structure. Because the energy distribution of the ground motion does not be considered in the response spectrum, so significant differences exist in total input-energy based on the response spectrum have led to great discreteness when applied to seismic design method based on energy. Considering the power spectrum of ground motion contains the concept of energy of inputs, in this paper, the method of determining seismic design inputs based on power spectrum is proposed to obtain more statistical results.

Firstly, adopting nonlinear dynamic analysis method, the frame sample is established to research on the structural total input-energy with the inputs selected by the response spectrum. Moreover, the energy duration is introduced to analysis the influence on the structural total input-energy. The results show that the discreteness of the structural total input-energy based on response spectrum is still very large even considering the energy duration factor. Then, the power spectrum of ground motions is calculated by Flourier transformation and smoothed by sliding average method through a rectangular window with a width of 0.5Hz. Taken the standard response spectrum of Chinese Code as the target power spectrum, the influence of the predominant frequency of the smoothing power spectrum and the natural frequency of structure on total input-energy of structure is analyzed. Consequently, taken the minimum error of the target power spectrum as the criterion, a new method of determining seismic design inputs based on the power spectrum is proposed. Finally, taken the total input-energy, the hysteretic energy ratio and the maximum interlayer displacement angle of the structure as the main response statistical factors, the proposed method is compared with the traditional method based on the response spectrum. The results show that the proposed method has less discreteness in the total input-energy of the structure and other indicators, which demonstrates that the proposed method is effective for determining seismic design inputs based on energy analysis.

Keywords: power spectrum; seismic design inputs; total input-energy; energy duration; predominant frequency

1. Introduction

The selection of seismic design inputs is one of the most difficult points in the application of time-history analysis method to the study of seismic performance of structures. In the seismic design method based on force, the acceleration response spectrum of seismic input is usually required to be consistent with the standard response spectrum of Chinese Code[1]. When the response spectrum of seismic input is close to the standard response spectrum, the maximum force response of the structure caused by the seismic input is close to the seismic action required by the standard response spectrum. It is applicable to select seismic inputs based on response spectrum in elastic seismic response analysis and force-based seismic design of structures, but there are limitations in elastic-plastic response analysis and energy-based seismic response analysis of structures[2].

Considering that the structural response under seismic is essentially the process of energy transfer and dissipation carried by seismic inputs in the structure. The power spectrum of ground motions reflect the energy distribution characteristics of seismic inputs in frequency domain, so there should be a strong internal relationship between the ground motion's power spectrum and the energy response of structure.

Therefore, the internal relationship between the ground motion's power spectrum and the structural energy response is studied, and a method of determining seismic design inputs based on power spectrum is proposed. Research contents and thoughts of this paper are as follows: Firstly, the limitation of seismic inputs selection method based on response spectrum in energy response is analyzed by building a frame structure model. In order to control the discreteness of the seismic inputs selection method based on response spectrum in the energy response, two methods to improve the accuracy of inputs selection and to supplement the energy duration will be considered. Then, the pre-processing of the record power spectrum and the target power spectrum is carried out, and the influence of the predominant frequency of the record power spectrum and the natural frequency of structure on total input-energy of structure is analyzed. The relationship between the record power spectrum and the total energy response of the structure is obtained, and the seismic inputs selection standard based on the power spectrum is proposed; Finally, the difference between the seismic inputs selection method based on response spectrum and the proposed method in the structural energy response analysis is compared, and the validity and statistics of the proposed method are verified.

2. Limitation of seismic inputs selection method based on response spectrum

At present, the commonly used seismic inputs selection method for structural seismic response analysis is based on response spectrum. In the method, the peak acceleration and spectrum characteristics of seismic inputs are considered, while the ground motion duration and the energy distribution not have been taken into account[3]. In this section, the seismic inputs selection method based on response spectrum is introduced firstly, and then the energy response of the structure under the earthquake excitation is analyzed by establishing the frame structure model. In addition, two methods to improve the accuracy of inputs selection and to supplement the energy duration will be introduced to verify the effectiveness of the discrete degree of control energy response.

2.1 Tow-frequency-domains (TFD) seismic inputs selection method based on response spectrum

Four seismic selection methods based on response spectrum are proposed by Yang Pu[4], and the TFD seismic inputs selection method is the most widely used and adopted by the Chinese Code. The specific method of TFD inputs selection is: the average error between the acceleration response spectrum value of the selected seismic inputs and the response spectrum value of the standard in the two frequency domains meets certain accuracy requirements (This accuracy requirement is hereinafter referred to as inputs selection accuracy), and the two frequency domains are defined as the platform ranges of the standard response spectrum $[0.1, T_g]$ and the frequency ranges near the natural period of structure $[T_1 - \Delta T_1, T_1 + \Delta T_2]$, The standard response spectrum is shown in Figure. 1. Based on the method of TFD seismic inputs selection, Chongqing University has compiled the seismic database and seismic inputs selection program[5].

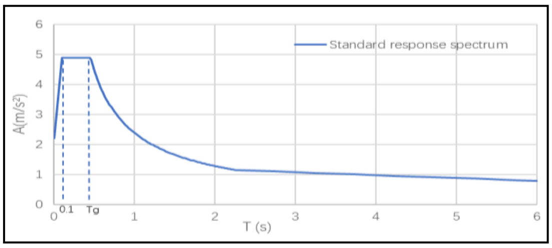


Fig. 1 – Standard response spectrum

In order to analyze the control effect of seismic inputs selection method based on response spectrum on structural energy response, a frame structure model is established according to Chinese Code[6]. The plane layout is shown in Figure. 2. The concrete strength grade of beams and columns is C30, and the size and reinforcement of beams and columns are shown in Figure. 3. The damping ratio of the structure is taken as $\xi = 0.05$, and the characteristic period of the site is taken as $T_g = 0.45s$. After calculation, the basic period of the structure is $T_1 = 0.744s$. It is suggested in reference [3] that the parameters in the TFD inputs selection method should be $\Delta T_1 = 0.05s$ and $\Delta T_2 = 0.2s$. The inputs selection accuracy of the platform ranges and the frequency ranges near the natural vibration period should be controlled at 18%. According to the TFD seismic inputs selection method, 90 seismic inputs are selected as shown in Table 1.

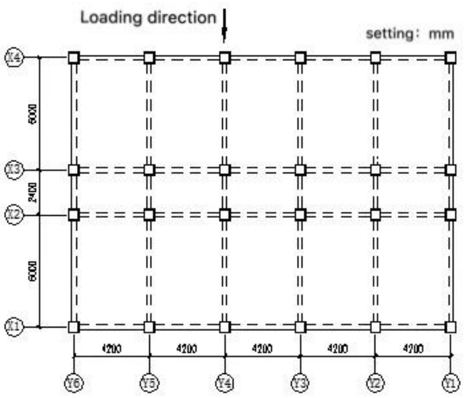


Fig. 2 –The plane layout

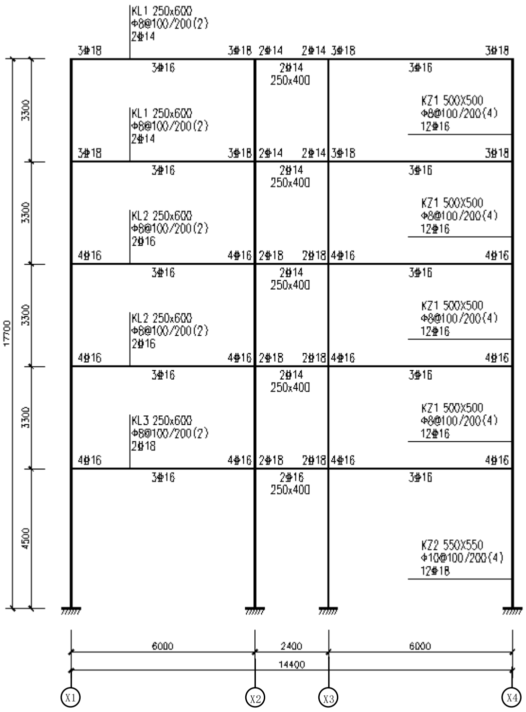


Fig. 3 – The size and reinforcement of beams and columns

2.2 Discreteness analysis based on total energy response of structure

The acceleration amplitude of seismic inputs selected by the TFD inputs selection method is adjusted to 2.2m/s^2, which input into the frame structure model, and the dynamic nonlinear analysis is carried out by CANNY[7]. The total input-energy (E_i), the total strain-energy (E_s), the hysteretic energy consumption ratio (E_s/Ei) and the maximum inter story displacement angle (θ_m) of the structure under the action of seismic inputs are obtained.

Table 1 shows the calculation results of the energy response of the structure under the excitation of each seismic input. From the results, the maximum value of E_i is 1141.6kN·m (NZD00144), the minimum value is 56.8 kN·m (USA02655), the difference is about 20 times; The maximum value of E_s is 706.9kN·m (USA01971), the minimum value is 20.4 kN·m (TAI01757), with a difference of about 35 times. It can be seen that the energy response results based on the TFD inputs selection are very discrete. From the displacement response point of view, the maximum value of θ_m is 1/40 (USA01971), while the minimum value is only 1 / 382 (PER00009), which also shows a strong discreteness.

Table 1 – Calculation results of structural energy response by TFD inputs selection

Seismic Inputs	E_i	E_s	E_s/Ei	θ_m	Seismic Inputs	E_i	E_s	E_s/Ei	θ_m
CHI00022	240.6	77.9	0.324	1/212	TAI03224	492.6	248.5	0.504	1/120
CHI00056	509.7	197.8	0.388	1/173	USA00011	443.6	188.2	0.424	1/180
CHI00096	801.5	426.3	0.532	1/122	USA00012	371.8	130.2	0.350	1/193
CHI00101	195.8	72.8	0.372	1/203	USA00068	440.0	186.2	0.423	1/140
CHI00102	195.8	72.8	0.372	1/203	USA00071	323.8	96.1	0.297	1/267
CHI00109	430.3	215.5	0.501	1/106	USA00117	825.9	461.2	0.558	1/83
IND00145	106.1	37.2	0.351	1/301	USA00533	950.4	428.4	0.451	1/112
ITA00028	220.8	76.3	0.346	1/173	USA00581	474.2	161.7	0.341	1/227
ITA00110	282.7	132.8	0.470	1/164	USA00590	130.6	41.2	0.315	1/273
ITA00140	197.8	75.5	0.382	1/221	USA00707	264.5	89.6	0.339	1/233
ITA00542	212.9	53.4	0.251	1/311	USA00721	493.5	243.8	0.494	1/173
ITA00563	173.6	60.5	0.349	1/222	USA00880	318.6	179.8	0.564	1/166
JAP00026	1005.5	664.1	0.661	1/56	USA00998	449.0	185.5	0.413	1/140
MEX00018	293.5	111.9	0.381	1/185	USA01004	323.9	96.1	0.297	1/267
NZD00084	255.9	69.1	0.270	1/300	USA01061	442.4	186.9	0.422	1/181
NZD00129	485.6	164.3	0.338	1/226	USA01062	373.4	131.1	0.351	1/192
NZD00144	**1141.6**	606.1	0.531	1/115	USA01075	319.3	137.6	0.431	1/166
NZD00248	969.3	603.5	0.623	1/82	USA01146	234.3	59.4	0.254	1/274
PAP00131	712.3	376.4	0.528	1/112	USA01441	951.5	429.1	0.451	1/113
PER00004	198.8	52.1	0.262	1/324	USA01477	454.7	153.0	0.336	1/231
PER00009	232.7	55.3	0.238	**1/382**	USA01537	263.1	88.9	0.338	1/235
PER00021	346.5	86.9	0.251	1/265	USA01545	497.2	245.1	0.493	1/172
PRC00003	941.5	465.5	0.494	1/102	USA01588	264.8	83.8	0.316	1/263
TAI00005	800.6	436.2	0.545	1/113	USA01897	259.9	140.9	0.542	1/110
TAI00012	316.4	145.4	0.460	1/156	USA01921	642.2	359.3	0.559	1/106
TAI00044	374.6	168.8	0.451	1/152	USA01923	732.5	408.9	0.558	1/109
TAI00685	822.3	503.6	0.612	1/75	USA01963	371.3	229.6	0.618	1/112
TAI00932	399.2	160.0	0.401	1/178	**USA01971**	965.4	**706.9**	0.732	**1/40**
TAI00966	452.3	193.9	0.429	1/157	USA02001	59.1	22.9	0.387	1/328
TAI01068	631.7	318.3	0.504	1/125	USA02010	66.7	25.7	0.385	1/239
TAI01077	219.0	79.9	0.365	1/189	USA02022	121.9	45.3	0.372	1/231
TAI01101	243.0	92.1	0.379	1/175	USA02048	145.9	79.4	0.544	1/162
TAI01119	263.4	85.8	0.326	1/262	USA02087	438.5	228.0	0.520	1/150
TAI01120	260.3	142.6	0.548	1/108	USA02160	231.0	107.2	0.464	1/172
TAI01133	797.8	445.8	0.559	1/91	USA02167	103.1	22.9	0.222	1/392
TAI01715	150.4	47.0	0.313	1/285	USA02405	722.1	408.1	0.565	1/81
TAI01757	64.2	**20.4**	0.318	1/310	USA02491	256.5	80.5	0.314	1/258
TAI01968	268.7	86.3	0.321	1/268	USA02551	256.7	140.3	0.547	1/110
TAI02003	191.1	55.7	0.291	1/259	USA02575	186.2	129.2	0.694	1/92
TAI02638	806.4	491.8	0.610	1/105	USA02593	375.7	232.2	0.618	1/109
TAI02766	141.2	40.7	0.288	1/333	USA02616	217.7	95.3	0.438	1/162

Seismic Inputs	E_i	E_s	E_s/Ei	θ_m	Seismic Inputs	E_i	E_s	E_s/Ei	θ_m
TAI02768	226.7	70.7	0.312	1/252	USA02619	705.1	388.3	0.551	1/113
TAI02910	424.3	261.5	0.616	1/79	**USA02655**	**56.8**	21.7	0.382	1/339
TAI02913	497.8	309.2	0.621	1/78	USA02662	78.5	34.6	0.441	1/202
TAI03214	1074.3	597.6	0.556	1/110	USA02664	67.6	26.3	0.389	1/228

2.3 Influence of seismic inputs selection accuracy on energy response of structure

In concept, the statistical value of ground motion's response spectrum can be improved by controlling the accuracy of inputs selection, but whether it can achieve better statistical value of the control energy response remains to be verified. Therefore, Table 2 shows the variation coefficient (δ= standard deviation/average value) of each energy response indexes calculated when the inputs selection accuracy is reduced to 15% and 12%. Table 2 shows that with the decrease of inputs selection accuracy, the number of selected seismic inputs decreases significantly. Although the discreteness of energy response indexes tend to decrease, the overall coefficient of variation is still large. For example, when the accuracy of inputs selection is 12%, the coefficient of variation of E_i and E_s are still as high as 0.6 and 0.79.

Table 2 – Coefficient of variation of structural responses on different inputs selection accuracy

Inputs selection accuracy(%)	Quantity of seismic inputs	δ_{E_i}	δ_{E_s}	δ_{E_s/E_i}	δ_{θ_m}
18	90	0.66	0.86	0.27	0.53
15	31	0.52	0.70	0.25	0.38
12	9	0.60	0.79	0.25	0.37

2.4 Influence of energy duration on energy response of structure

The relationship between the energy duration and the structural energy response is considered closely. In this paper, the relative energy duration of Trifunc&Brady[8] is introduced to investigate the relationship between the energy duration and the total input-energy.

The definition formula of energy duration is:

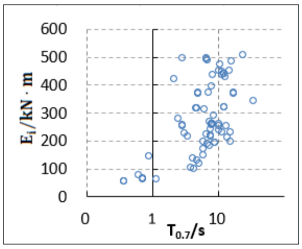
$$T_e = t_2 - t_1 \tag{1}$$

$$E=\int_{t_1}^{t_2} a^2 dt \tag{2}$$

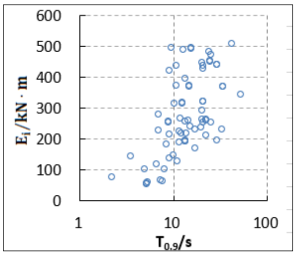
The relationship between energy duration and total input-energy is analyzed under the conditions of 70% energy duration and 90% energy duration. 70% energy duration is defined as the duration between 10% and 80% of total energy of seismic input, and 90% energy duration is defined as the duration between 5% and 95% of total energy of seismic input.

Figure. 4 (a) and (b) respectively show the relationship between 70% energy duration and 90% energy duration and the total input-energy. It can be seen that the distribution range of energy duration is from 0 s to 100 s, and there is no clear corresponding relationship between energy duration and the total input-energy. Therefore, it is difficult to reduce the discreteness of energy response indexes by controlling energy duration.

In this section, according to the analysis of the energy response law of the frame structure model, it can be concluded that the discreteness of the structural energy response indexes based on response spectrum is still very large even considering the inputs selection accuracy and energy duration, and it is difficult to get statistical results.



(a)



(b)

Fig. 4 – Relationship of energy duration and energy response based on the TFD inputs selection

3. The record power spectrum and the target power spectrum

Power spectrum has the advantage of describing the characteristics of energy distribution. Therefore, the standard based on response spectrum stipulated by Chinese Code is converted to power spectrum, and the seismic inputs selection based on power spectrum is studied, which is expected to form a new method of seismic inputs selection.

In this section, the power spectrum of inputs are analyzed, and a smoothing method of power spectrum is proposed. The influence of the predominant frequency of the record power spectrum and the natural frequency of structure on total input-energy of structure is analyzed. The relationship between the record power spectrum and the total energy response of the structure is established.

3.1 The relationship between the record power spectrum and the total energy response of the structure

The principle of power spectrum calculation of seismic inputs is to treat a seismic input as a random sequence $x(n)$ containing N observation data, and the energy of this sequence is considered to be limited. The discrete Fourier transform of $x(n)$ is directly calculated to obtain the Fourier spectrum. Then the square of its amplitude is taken and divided by N as the real power spectrum of the sequence. The power spectrum of real seismic input is serrated with violent fluctuation, so it is impossible to distinguish the exact position of the peak point of the spectrum. Considering the strong randomness of seismic inputs, the effect of local sharp fluctuation on structural response is not significant. Therefore, by smoothing the spectrum, not only the essential characteristics of the original inputs will not be distorted, but also the real properties of the spectrum will be highlighted.

In this paper, the sliding average method is used to smooth the real power spectrum of seismic inputs. The width of the rectangular window is 0.5Hz, and the smoothed power spectrum is called the record power spectrum. The frequency corresponding to the maximum value of the record power spectrum is defined as the predominant frequency f_m of the record power spectrum.

In order to explore the relationship between the different total input-energy and the power spectrum characteristics of seismic inputs, six seismic inputs with larger, medium and smaller total input-energy calculated in the previous section by TFD inputs selection method are selected, which correspond to the first, second and third groups in Table 3, and the characteristics of the record power spectrum are analyzed.

When the structure is subjected to seismic action, the structure softens due to damage, the natural frequency of the structure becomes smaller, so the natural frequency of the structure changes in the process of the seismic input. Figure. 5 is the record power spectrum of the selected seismic inputs. It can be found that with the deepening of structural damage, the natural frequency of the structure encountering the first group of seismic inputs is close to the predominant frequency of the seismic inputs; The natural frequency of the structure encountering the second group of seismic inputs deviates from the predominant frequency of the seismic inputs. However, in the frequency range where the natural frequency of the structure may change, the power spectrum amplitude of the seismic inputs is not small; The natural frequency of the structure encountering the third group of seismic inputs deviates from the predominant frequency of the seismic inputs, but the power spectrum amplitude of the seismic inputs is very small. Therefore, the total input-energy of the structure under the action of ground motions is related to the spectrum characteristics of the seismic inputs' power spectrum near the natural frequency of the structure. Then, if the record power spectrum of seismic inputs is similar, the total input-energy of the structure is also close.

Through the relationship between the total input-energy of the structure and the record power spectrum of seismic inputs, a method for selecting seismic inputs can be proposed. Taken a standard power spectrum as the target power spectrum and chosen the seismic inputs whose record power spectrum is similar to the target power spectrum, the total input-energy response of these seismic inputs is less discrete. The core of this method includes two aspects, one is to establish the target power spectrum, the other is to establish the matching method between the record power spectrum of seismic inputs and the target power spectrum.

Table3 – Energy response of seismic inputs

Groups	seismic inputs	$E_i/(kN\cdot m)$	$E_s/(kN\cdot m)$	E_s/E_i	f_m/Hz
Group one	USA01971	965.4	706.9	0.732	0.586
	JAP00026	1005.5	664.1	0.661	0.366
Group two	CHI00056	509.7	197.8	0.388	4.309
	CHI00109	430.3	215.5	0.501	3.076
Group three	USA02010	66.7	25.7	0.385	2.490
	USA02655	56.8	21.7	0.382	1.611

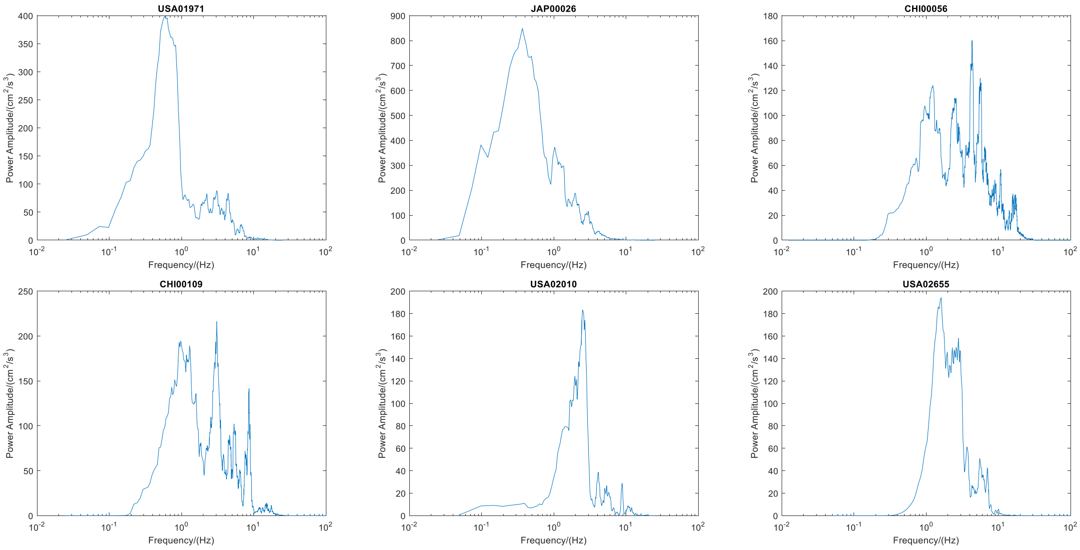


Fig. 5 – Power spectrum of seismic inputs

3.2 Establish the target power spectrum

In order to be consistent with the seismic design of Chinese Code, the target power spectrum is transformed from response spectrum according to the method of reference [10]. In addition, reference [11-13] gives different power spectrum models and parameter values.

Considering that Hu Yuxian's model can accurately consider the power spectrum value in the low frequency range, the power spectral density function of reference [12] is adopted:

$$S(w)=\frac{\omega^6}{\omega^6+\omega_c^6}\cdot\frac{\omega_g^4+4\xi_g^2\omega_g^2\omega^2}{(\omega_g^2-\omega^2)^2+4\xi_g^2\omega_g^2\omega^2}S_0 \qquad (3)$$

In the formula, S_0 is the white noise input of the acceleration of the bedrock. ξ_g and ω_g are the damping ratio and the predominant frequency of the foundation soil. ω_c is the parameter to reduce the low-frequency content.

According to the site type of the frame structure model in this paper, reference [12] for parameter value of power spectrum: $\xi_g = 0.72$, $\omega_g = 15.71$, S_0=87.6, $\omega_c = 3.11$. As shown in Figure. 6, which is the target power spectrum of this paper.

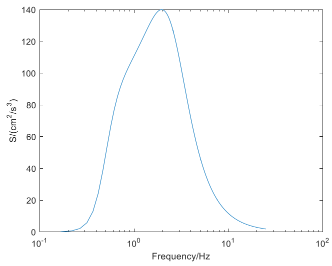


Fig. 6 – Target power spectrum

3.3 Principles of seismic design inputs selection method

The basic idea of establishing the matching method between the record power spectrum of seismic inputs and the target power spectrum is to exclude the seismic inputs that do not match the target response spectrum in the basic database of seismic inputs satisfying certain magnitude, epicenter distance and shear wave velocity range, and the remaining is effective seismic inputs.

According to the study of the relationship between the record power spectrum and the total energy response of the structure in Section 3.1, there are four types of record power spectrum that do not match the target power spectrum:

(1) The predominant frequency of the record power spectrum is less than the natural frequency of the structure.

(2) The area of the record power spectrum in the natural frequency change range of the structure is too large or too small.

(3) The area enclosed by the full frequency range of the record power spectrum is too large or too small.

(4) The predominant frequency of the record power spectrum is larger than the structural natural frequency, but it appears the second peak(secondary predominant frequency) in the less than the structural natural frequency, and the secondary predominant frequency is smaller than the structure natural frequency.

Based on the above types of record power spectrum which do not match the target power spectrum, the selection principles of seismic inputs are proposed:

(1) The range of magnitude(M) and epicenter distance(R) corresponding to the given intensity is determined according to intensity attenuation law. The range of shear wave velocity v_{s30} is determined by site type, which is used to determine the basic database of seismic inputs.

(2) The power spectrum of seismic inputs in the previous step is obtained and smoothed. According to the smoothed record power spectrum and the target power spectrum, the mean deviation between 0.1Hz and 10Hz of the total frequency range is calculated, which is called the total mean deviation (Δ_{total}).

$$\Delta_{total} = \frac{\sum_{i=1}^{N} \left| S^{Record}(i) - S^{Target}(i) \right|}{N} \qquad 0.1\text{Hz} \le f(i) \le 10\text{Hz} \tag{4}$$

In the formula, $S^{Record}(i)$ is the power spectrum amplitude of point i of the recorded power spectrum; $S^{Target}(i)$ is the power spectrum amplitude of point i of the target power spectrum; f(i) is the frequency of point i; N is the total number of points with the frequency between 0.1Hz and 10Hz.

(3) Determining a variation range of natural vibration frequency of structures from natural period of structures. Mean deviation in the frequency variation is calculated, which is interval mean deviation (Δ_{int}).

$$\Delta_{int} = \frac{\sum_{i=j+1}^{j+m} \left| S^{Record}(i) - S^{Target}(i) \right|}{m} \qquad \begin{array}{l} f(j+1) \le f(i) \le f(j+m) \\ f_{low}^{int} = f(j+1), f_{high}^{int}(j+m) \end{array} \tag{5}$$

In the formula, f_{low}^{int} is the lower bound of the structural natural frequency variation section, corresponding to the j+1 point of the total frequency section, f_{high}^{int} is the upper bound of the structural natural frequency variation section, and corresponds to the j+m point of the total frequency section.

(4) The predominant frequency of each record power spectrum is calculated, the predominant frequency of record power spectrum is less than the natural frequency of the structure is excluded, 1.05 times of the period can be considered ($f_m<0.95f_0$). The first type of record power spectrum is excluded.

(5) When the predominant frequency of the record power spectrum is larger than the natural frequency of the structure, the secondary predominant frequency of the record power spectrum(f_m^1) is calculated, and the seismic inputs of $f_m^1 < 0.75 f_0$ is excluded. The fourth type of record power spectrum is excluded.

(6) The total mean spectral values (S_{total}^{mean}) and interval mean spectral values (S_{int}^{mean}) of the target power spectrum are calculated, and then the interval mean deviation (Δ_{int}) is limited to not exceed 50% of the interval averaged spectral values. The second type of record power spectrum is excluded.

$$S_{total}^{mean} = \frac{\sum_{i=1}^{N} S^{Target}(i)}{N} \qquad S_{int}^{mean} = \frac{\sum_{i=j+1}^{j+m} S^{Target}(i)}{m} \qquad \Delta_{int} \le 50\% \times S_{int}^{mean} \tag{6}$$

(7) The initial value(γ) of the ratio of the total mean deviation to the total mean spectral value is set, within which the seismic inputs is selected. That is to say, the number of seismic inputs of the third type record power spectrum is controlled.

$$\Delta_{total} \le \gamma \times S_{total}^{mean} \tag{7}$$

4. Verification of seismic inputs selection method based on power spectrum

In this section, the proposed seismic inputs selection method is verified by the frame structure model. The seismic inputs selection method proposed in this paper is compared with the seismic inputs selection method based on response spectrum. Taken the energy response results as the statistical factors, the energy discrete degree calculated by the two seismic inputs selection methods is analyzed.

4.1 An example of seismic inputs selection method based on power spectrum

PEER NGA-West2[14] is used as the source of basic database, according to the power spectrum selection standard in Section 3.3, the frame structure in Section 2.1 is taken as an example to select the seismic inputs.

8 seismic inputs are selected according to the inputs selection method based on power spectrum. The record power spectrum parameters of 8 seismic inputs are shown in Table 4, and the comparison relationship between the record power spectrum and the target power spectrum are shown in Figure. 7. The results show

that the total mean deviation and interval mean deviation of TAF111 are the smallest, and the shape of the record power spectrum is similar to the target power spectrum; The total mean deviation and interval mean deviation of other seismic inputs meet the principle of inputs selection method based on power spectrum.

The results show that 8 seismic inputs are obtained by using the seismic inputs selection method based on the power spectrum in this paper. The calculation deviation and comparison figures show that the record power spectrum of these seismic inputs is very close to the target power spectrum, which shows that the seismic inputs selection method based on the power spectrum can effectively select the seismic inputs whose record power spectrum is similar to the target power spectrum.

Table 4 – The record power spectrum parameters of 8 seismic inputs

Seismic inputs	Δ_{total}	Δ_{int}	f_m	f_m^1
ELC180	16.84	49.31	1.33	1.33
TAF111	16.47	12.14	2.31	1.35
ORR291	25.60	25.78	2.04	1.21
L01111	31.12	44.62	1.66	1.32
CHI012	25.05	52.38	1.44	1.44
BOV000	29.72	21.10	4.46	1.43
C05270	28.35	54.08	2.33	1.44
PVY045	30.72	20.75	1.94	1.15

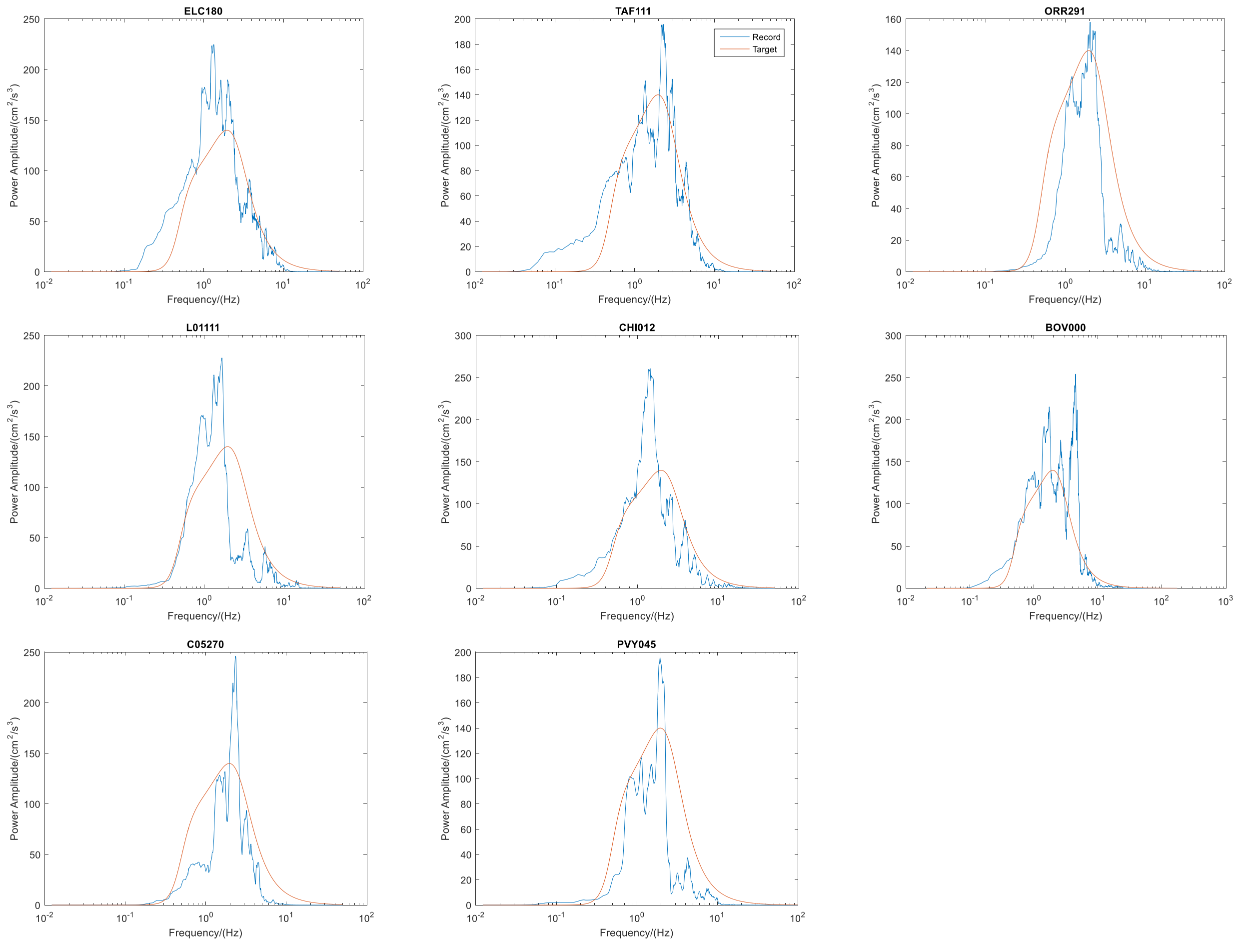


Fig. 7 – Target power spectrum and record power spectrum

4.2 Discreteness analysis of seismic inputs selection method based on power spectrum for total energy response evaluation of structure

In order to further analyze the applicability of the seismic inputs selection method based on power spectrum to the calculation of structural energy response from a quantitative point of view, this section takes the frame structure model with inputs PGA = 220gal, energy response indexes of the structure are calculated, and the statistical results are shown in able 5. The coefficient of variation of each energy response index of the structure calculated by two seismic inputs selection methods are shown in Figure. 8.

In conclusion, the seismic inputs selection method based on power spectrum can effectively reduce the discreteness of the total input-energy, the total strain-energy, the hysteretic energy ratio and the maximum inter story displacement angle of the structure compared with the seismic inputs selection method based on response spectrum, which shows that the proposed method is more applicable and statistical for structural energy response analysis.

Table 5 – Total energy response under selected seismic inputs

Seismic Inputs	$E_i/(kN\cdot m)$	$E_s/(kN\cdot m)$	E_s/E_i	θ_m
ELC180	551.0	270.9	0.492	1/126
TAF111	446.1	190.3	0.427	1/178
ORR291	269.6	106.4	0.395	1/166
L01111	641.3	371.5	0.579	1/78
CHI012	506.7	209.3	0.413	1/179
BOV000	496.7	207.9	0.418	1/172
C05270	325.1	101.8	0.313	1/285
PVY045	326.8	150.5	0.460	1/153
Mean	445.4	201.1	0.44	1/149
Coefficient of variation	0.27	0.41	0.17	0.38

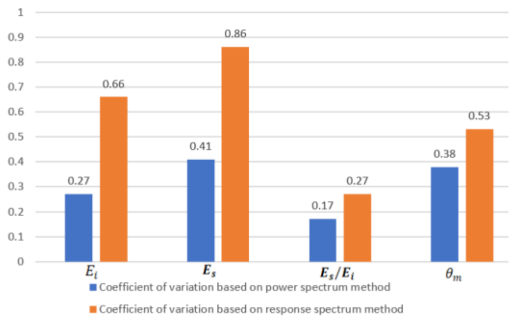


Fig. 8 – Comparison of coefficient of variation of energy response indexes

5. Conclusion

In this paper, through the frame structure model, the limitation of seismic inputs selection method based on response spectrum in structural energy response analysis is studied, and the applicability of seismic inputs selection method based on power spectrum in structural energy analysis is discussed. The main conclusions are as follows:

(1) The results of the total energy response of the structure calculated by the seismic inputs selection method based on the response spectrum have great discreteness, and the discreteness of the total energy response of the structure has not been improved obviously when the seismic inputs selection accuracy and energy duration are considered.

(2) The relationship between the total input-energy of the structure and the predominant frequency of the record power spectrum and the natural frequency of the structure under the seismic inputs is verified. A seismic inputs selection standard based on the power spectrum is proposed, and a method of seismic inputs selection based on the power spectrum is established.

(3) The seismic inputs selection method proposed in this paper is used for seismic inputs selection combined with the frame structure model. The analysis results show that the seismic inputs selection method based on power spectrum can effectively reduce the discreteness of structural energy response analysis results, which shows that the seismic inputs selection method proposed in this paper has stronger applicability and statistics for structural energy response analysis.

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