Influencing Factor Analysis of the Hysteretic Energy Responses for Seismic Frame Structures

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ABSTRACT

One of the important issues in the research field of analyzing performance of seismic frame structures is the analysis of total input earthquake energy for seismic frame structure under earthquake action and hysteretic energy responses due to plastic deformation of structural components. Total input energy and hysteretic energy are influenced by various structural dynamic parameters and earthquake parameters, such as strength and stiffness of a structure, amplitude value, frequency quality and duration of an earthquake, and other many factors. The total input earthquake energy and hysteretic energy are analyzed by employing time-history methods and using a great deal of earthquake digital records as input data. Various different structural dynamic parameters and earthquake parameters are considered in the analysis of time-history method. The proportion of hysteretic energy to total input energy is calculated. The outcome of this analysis indicates that the structural dynamic parameters and earthquake parameters have not significant influence on this proportion above. The simplified analysis method of hysteretic energy for high-rise frame structures is proposed in this paper. The research result is research basis for analysis of performance of seismic frame structure.

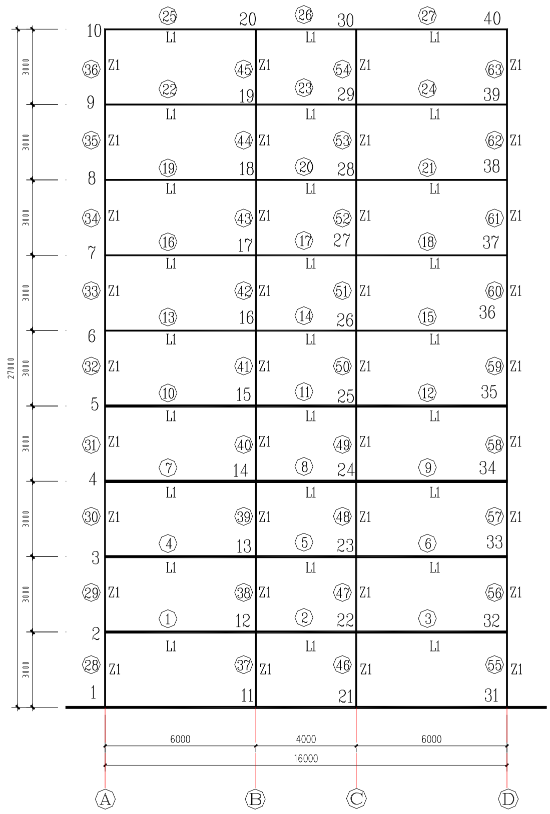
KEYWORDS: seismic frame structures, hysteretic energy, influencing factor

1. INTRODUCTION

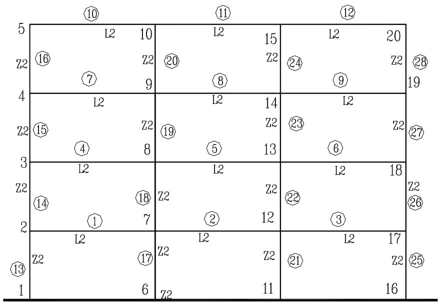
One of the important issues in the research field of analyzing performance of seismic frame structures is the analysis of total input earthquake energy for seismic frame structure under earthquake loading and hysteretic energy responses due to plastic deformation of structural components. Total input energy and hysteretic energy are influenced by various dynamic characteristic of structure, ground motion characteristic and other many factors. These factors include ground motion parameters in amplitude value, frequency spectrum and duration as well as structure's various dynamic parameters. Then these parameter influences on total input earthquake energy, hysteretic energy of the frame structure and proportion of hysteretic energy to total input energy are analyzed. This work provides research basis for analysis of performance of seismic frame structure. The influence of ground motion characteristic and dynamic characteristic of structure on total energy and hysteretic energy are discussed through examples of seismic frame structure in this paper.

2. CALCULATED MODEL OF PLANE STRUCTURES, COMPONENT ELEMENT DIVISION AND HYSTERETIC MODEL

In order to accord with actual engineering situation, namely consider different earthquake parameters combination, two kinds of plane frame structures for total 10 examples are designed according to Chinese Code for Concrete Structure Design and Chinese Code for Seismic Design of Building. Structure I is 9-layer plane frame structure and structure II is 4-layer plane structure considering 7, 8 magnitude of seismic fortification intensity. In these two kinds structure, beam section dimensions are not chanced and column section dimensions are different, ranging from 500mm×500mm to 600mm×600mm in 9-layer plane structure and 450mm×450mm to500mm×500mm in 4-layer plane structure. In these ten structures, six are designed based on 7-degree seismic fortification intensity and four are based on 8-degree seismic fortification intensity. These structures are with floor uniform live load of 2.0kN/m^2, beam line load of 7kN/m. filler wall of aerated concrete blocks, structure space between of 6m and concrete grade of C30. Calculated model of plane structure, element division and component hysteretic model are shown in Figure 1.



Beam and column elements for structure I



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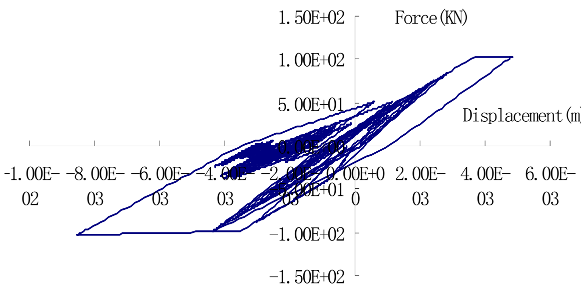
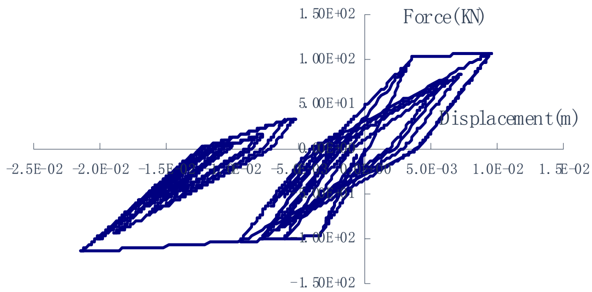


Tri-linear hysteretic curve



Twi-linear hysteretic curve

2. INFLUENCE OF GROUND MOTION PARAMETERS ON ENERGY RESPONSES OF SEISMIC FRAME STRUCTURE

Ground motion is mainly characterized by amplitude value of ground motion, frequency spectrum and duration. Amplitude value of ground motion is fixed depending on records of acceleration history. For different need in analysis, people propose different concept of amplitude value [3], such as peak acceleration, effective peak acceleration, equal response spectrum effective peak acceleration, sustained acceleration, probabilistic effective peak, static equivalent acceleration and equivalent simple harmonic amplitude and so on. Literature [4] chooses typical El-Centro and Taft seismic waves. In literature [4], peak amplitude of these two seismic waves are modulated as 220gal, 400gal and 620gal in terms of peak acceleration (PGA), effective peak acceleration (EPA), sustained acceleration (as) defined in the literature [3], and modulated ground motions are input to calculate hysteretic energy response of several plane frame structures. Literature [4] discusses influence of ground motions which are selected according to differently defined amplitude on structural hysteretic energy. The outcome is shown in Fig. 2 which hysteretic energy history curve under different defined amplitudes.

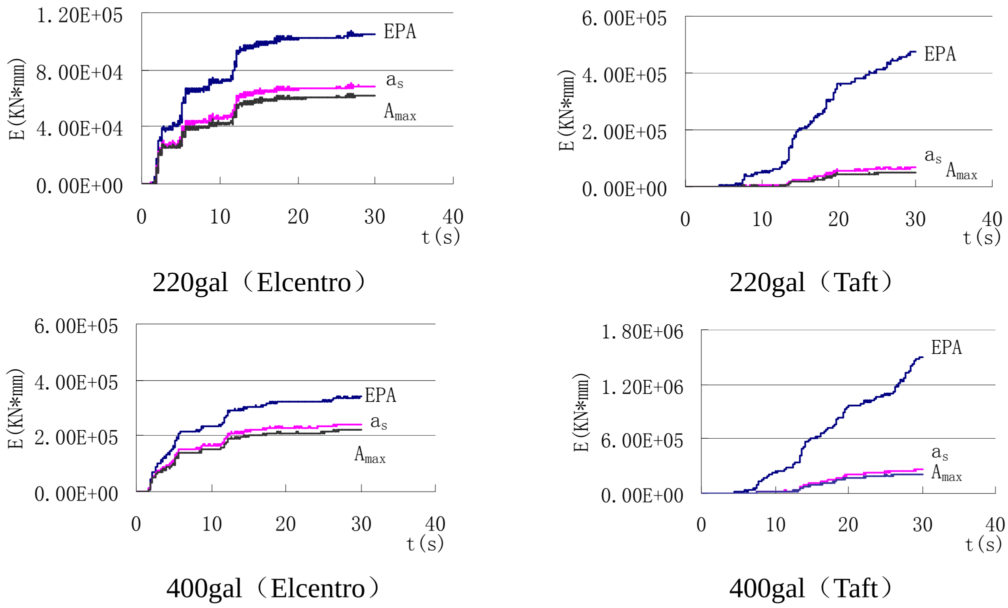


Fig. 2 The hysteretic energy curve of structure5 under different crest value definition

Attention: A_{max} is GPA in this figure

The outcome indicates that in the same defined ground motion input, for the same structure and under changeless frequency spectrum and duration of ground motion, the bigger amplitude of ground motion is, the bigger caused structural accumulated hysteretic energy is. At the mean time, different time-history curves of structural hysteretic energy adopting different amplitude definition are gotten. Among these curves, the hysteretic energy which is calculated with effective peak acceleration (EPA) is much bigger than the one which is gotten by choosing amplitude definition of PGA and as, moreover this difference is bigger with increase of seismic intensity.

When amplitude definition of EPA are adopted, about four times magnitude difference between accumulated hysteretic energy which is calculated with inputting the same amplitude El-Centro wave and Taft wave are found in Fig.2. But hysteretic energy are close and the difference are less than 20% with inputting waves which is of the same amplitude situation and choosing the amplitude definition of PGA and as. The current amplitude definition of PGA adopted by Seismic Design Code of Building [2] (GB50011-2001) is selected to define amplitude of ground motion in this paper, and the amplitudes respectively are 220 gal, 400 gal considering rare seismic intensity of 7and 8.

The frame structure with different nature vibration period and under different condition such as site soil, epicentral distance and so on will suffer different seismic damage when a ground motion composed of variety of frequency spectra components is input. Spectrum characteristic of ground motion could be represented by Fourier spectrum, power spectrum and response spectrum. It is very complicated that spectrum characteristic of ground motion is mainly influenced by dynamic characteristic of seismic source, magnitude, propagation distance and site condition. Spectrum characteristic of ground motion is one important factor that impacts structural response. In time-domain analysis response spectrum is widely adopted. Response spectrum describe not only spectrum characteristic of ground motion but also depict certain seismic response characteristic of structures, so seismic design in many countries select response spectrum to depict spectrum characteristic of ground motion. If peak acceleration of ground motion and duration maintain changeless and structural nature vibration period and predominate period of ground motion are closer, structural response is bigger so as to induce the augment of hysteretic energy. The research point out that spectral factors of seismic waves greatly affect on the distribution of total energy to damping dissipation energy and hysteretic energy, and the effect is relatively complicated. From general trend, we could see the longer predominant period is, the bigger structural damping dissipation energy and hysteretic energy would be. Correspondingly damping dissipation energy and hysteretic energy would be smaller with the decrease of predominant period.

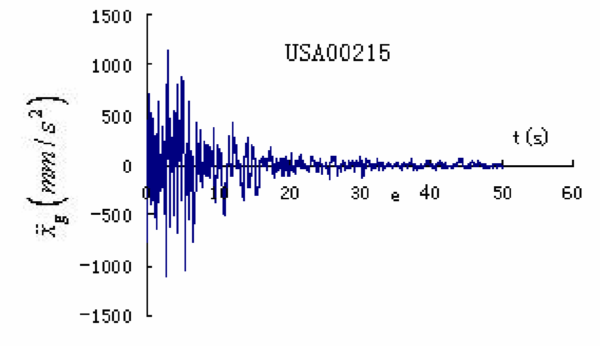
3. SELECTION OF GROUND MOTION BASED ON CONCEPT OF DOUBLE-INDEX AND ENERGY

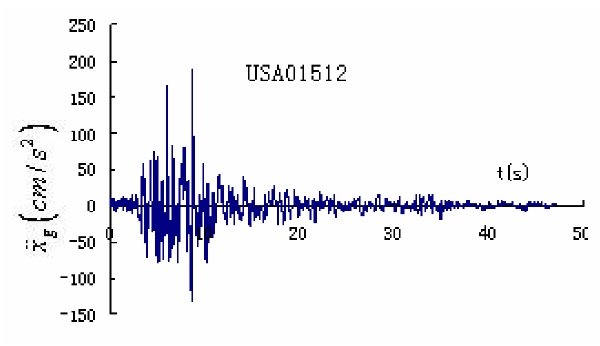
In order to find out statistically significant response of structural hysteretic energy, using a great deal of earthquake digital records as input data, in this paper the method of double-index which use two frequency bands control is adopted to select the seismic waves. First, control average value in [0.1， T_g] platform segment of acceleration response spectra of seismic recording, requiring difference between average value of acceleration spectra of seismic recording and the one of design response spectra is less than 20%; second, control average value in [T_1-△T_1， T_1+△T_2] segment of acceleration response spectra, △T_1 and △T_2 equals 0.1s in this paper, to require difference between this average value and one of design response spectra is less than 10%. In this paper these selected waves are input and designed 10 plane frame structures are analyzed, the outcome is shown in Table 1.

Table 1 The hysteretic energy of structure under the wave selection with two indexes

Structure	Wave number	Hysteretic Energy（N．m）	Average Value（N·m）	Standard deviation	Coefficient of Variation
1	62	5.34E+04～6.18E+06	5.78E+05	7.178E+05	1.242
2	53	5.67E+04～6.376E+06	5.961E+05	6.813E+05	1.143
3	56	5.913E+04～6.81E+06	6.162E+05	6.617E+05	1.074
4	51	5.67E+04～7.19E+06	6.367E+05	8.019E+05	1.261
5	73	6.313E+04～7.61E+06	6.952E+05	7.321E+05	1.053
6	43	1.682E+03～2.321E+05	1.937E+04	2.513E+04	1.297
7	41	1.834E+03～2.693E+05	2.071E+04	2.349E+04	1.134
8	46	1.915E+03～2.914E+05	2.163E+04	2.374E+04	1.098
9	36	1.934E+03～2.893E+05	2.371E+04	3.134E+04	1.321
10	32	2.176E+03～3.021E+05	2.731E+04	2.934E+04	1.074

In terms of analyzing Table 1, we could find that when we select the seismic waves by the method of double-index, simultaneously considering amplitudes of ground motion and spectrum characteristics, hysteretic energies of the same structure under different seismic waves are different. Furthermore, the difference even reaches to 2 orders of magnitude. This is mostly because selecting wave scheme of double-index ignores duration of main earthquake segment of ground motion. This paper selects 3 kinds of seismic waves basing on duration definition, shown in Fig. 3.Only several figures of typical waves are given in this paper because of the limit of length.





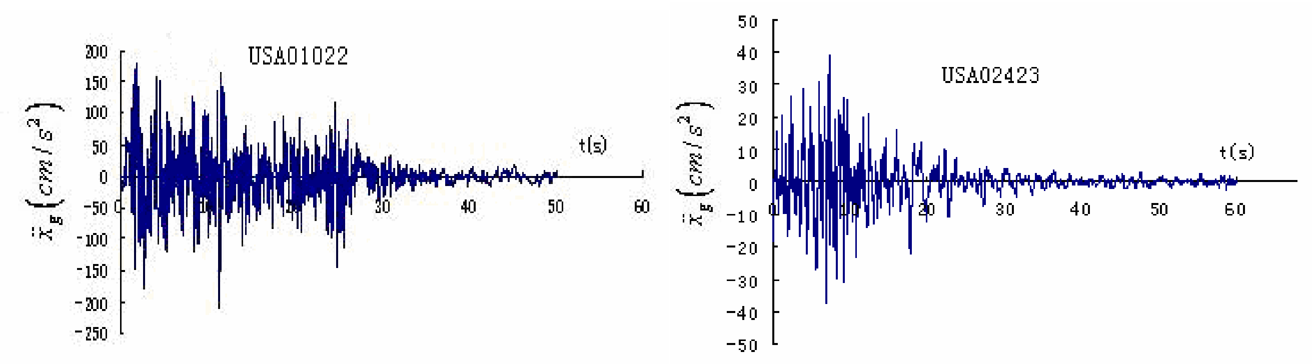


Fig. 3 Earthquake acceleration

4. ANALYZING INFLUENCING FACTORS OF PROPORTION OF STRUCTURAL HYSTERETIC ENERGY TO THE TOTAL INPUT ENERGY

The amplitudes of seismic waves are modulated according to amplitudes of 220gal and 400gal in seismic intensities of 7.8 when the total input energy and hysteretic energy are computed. The structures absorb the energy from the ground motion, only a small part is transformed into kinetic energy and elastic strain energy, and most part is dissipated through damping dissipation energy and plastic strain energy. Damping dissipation energy plays a decisive role when structures are still in the elastic phase. But when structures enter nonlinear phase, plastic energy dissipation incessantly increases with the augment of plastic deformation. So the proportion of damping dissipation energy to total input energy would ceaselessly decrease. With the development of nonlinear deformation, the proportion of structural hysteretic energy to total input energy constantly rises. Under multi-waves input, statistical outcomes of proportions of hysteretic energy to total input energy are shown in Table.2 and Fig.4.

Table 2 The energy of structure under the wave selection

Seismic Wave	Elastic Dissipation Energy（N*m）	Hysteretic Energy（N*m）	Total Input Energy（N*m）
USA00215	1.594E+04	8.471E+04	3.136E+05
USA01512	6.41E+04	1.8637E+05	3.932E+05
USA01022	5.03E+04	2.576E+05	4.194 E+05
USA02423	2.916E+04	1.164E+05	1.973 E+05

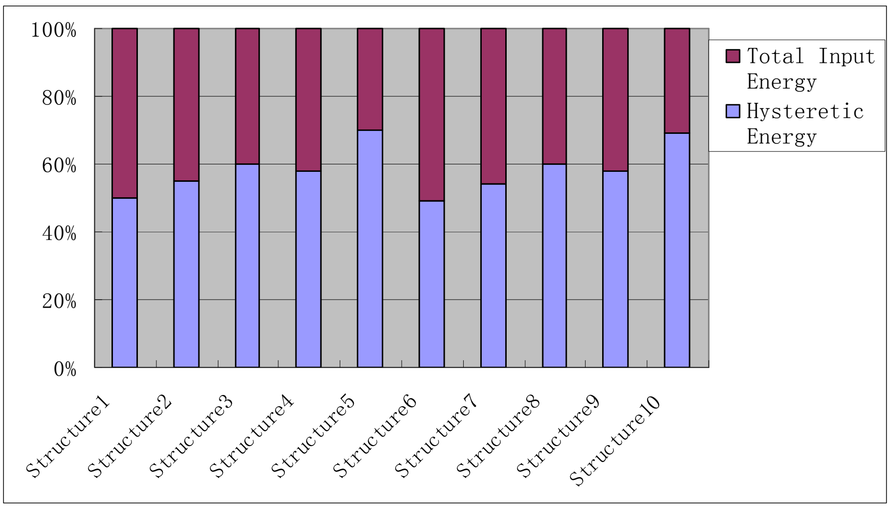


Fig.4 The proportion of hysteretic energy in the total input energy of structures

The outcomes show that for the same structures the proportion of hysteretic energies to total input energy is much large. If seismic intensity of 7 is raised to 8, this proportion would enhance, but this augment will not be more than 20%. Comparing with single wave analyzing outcome of the same structure in literature [4], we could find that with different waves as input data, the proportion of hysteretic energy of the same structures to the total energy has little change. Furthermore, with the improvement of seismic intensity the proportion has no evident change law. This phenomenon accords with the outcomes in literature [6] which discusses the proportion of structural hysteretic energy to total input energy in the single freedom system. These outcomes are: the proportion of hysteretic energy to total input energy only depends on dynamic characteristics of structural itself, and it has nothing to do with characteristics of ground motion. This is also proved in Fig. 4 in this paper. In this paper two-line hysteresis model and tri-line hysteresis model are adopted. In tri-line hysteresis model, due to considering opening point stiffness of components reduce earlier in comparing with two-line hysteresis model, therefore hysteretic energy is bigger and the proportion is larger, but this difference is small just about 2%-3%. From the Fig. 4, we could find that strong column-weak beam structures with stronger linear stiffness of column is of stronger lateral resisting ability and larger dissipation energy through plastic deformation. So it could be considered that structural stiffness is important factor which influences the proportion of hysteretic energy to total input energy. We could change structural strength and stiffness to improve and enhance structural seismic performance.

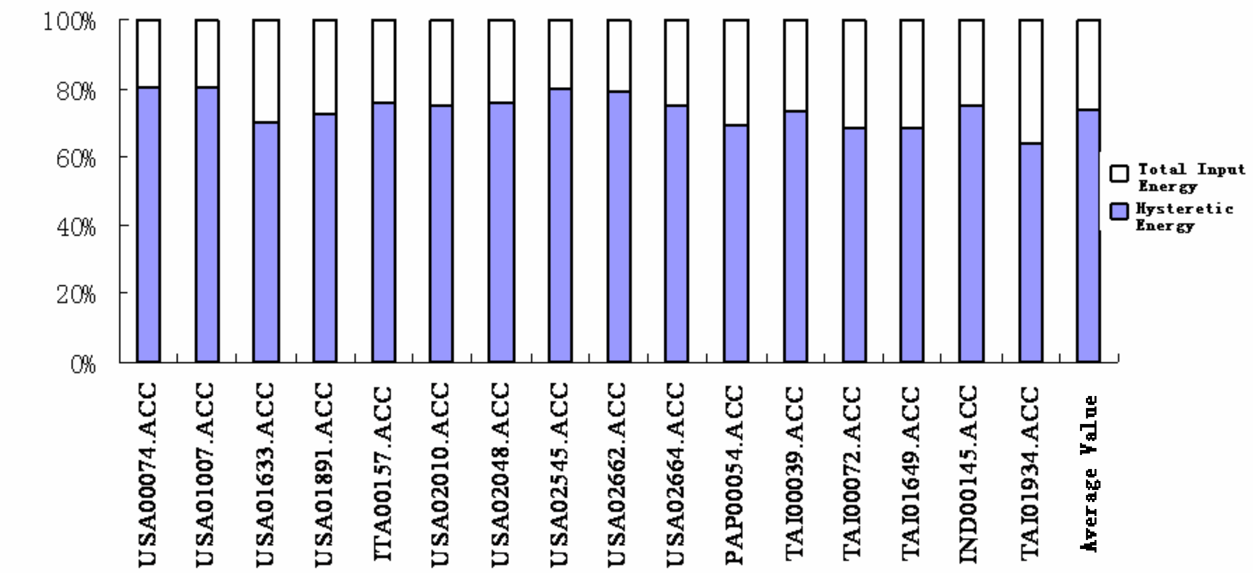


Fig5 The proportion of hysteretic energy in the total input energy of a structure

5. CONCLUSION AND SUGGESTION

Hysteretic energy of seismic structures is relative with not only dynamic characteristics of input ground motion but also dynamic characteristic of structures. Amplitude of ground motion, spectrum characteristic and duration of rare earthquake are all important factors that affect hysteretic energy. Structural stiffness and selection of hysteretic restoring force model are also very greatly influential. But the proportion of structural hysteretic energy to total input energy is not affected by dynamic characteristics of ground motion. For a certain structure, we could first calculate the total input energy of the structure, namely total energy of ground motion, and then multiply this total energy by a certain proportion coefficient to get structural total hysteretic energy. Performance of dissipation energy could be observed by structural total hysteretic energy. In order to get simplified analysis method of evaluating structural total dissipation energy, the total input energy and the proportion coefficient must be calculated first. The total input energy could be calculated by elastic analysis for structures. The proportion of hysteretic energy to total input energy only basically relate with structural stiffness. But duo to great difference of structure forms in practice engineering and various structural forms with different dynamic characteristics, this proportion coefficient have to be computed by a great deal of statistical analysis.

Computing proportion ratio for various structural forms will be performed in lateral working.

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