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STUDY ON THE SEVEREST DESIGN GROUND MOTIONS

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SUMMARY

For the seismic design and structure analysis, especially for the huge complex structure, one of the most important tasks is selecting the proper real ground motions for design. The idea of selecting the severest design ground motions is presented in this paper. The severest design ground motions should be selected from the existing strong earthquake ground motions that can drive the structure to its critical response and thereby result in the highest damage potential.

The concept of the severest design ground motions is presented in the paper. A comprehensive method for estimating damage potential of ground motions is developed in this paper and it has been used in selecting the severest design ground motions. The severest design ground motions corresponding to four different classes of site conditions and three different period ranges of structure are attained. The three period ranges of structure are long period range (1.5-5.5s), middle period range (0.5-1.5s) and short period range (0.0-1.5s). At the end, the validity and reliability of the severest deign ground motions are verified preliminary by several numerical calculations.

INTRODUCTION

It is essential to select suitable real ground motions for structure to be checked. In fact, almost all the earthquake-resistance codes have the regulation: the important structures, such as long-span bridges, irregular structures particularly, structures of classification A, the high-rise buildings of which height exceed the limitation, must be calculate complementarily with at least two real records and one man-made record. So how to select the proper real ground motions for seismic design and analysis is a very important problem.

At present, the EL CENTRO record (NS) of 1940 and TAFT record of 1952 are in the first place to be considered in the seismic design and structure analysis. What is the reason for selecting such records, whether the records are the severest design ground motions, and which records can be considered as the severest design ground motions are the issues this paper tries to solve. Study (Naeim and Anderson[2]) shows that the values of peak acceleration (PA), peak velocity (PV), peak displacement (PD), effect peak acceleration (EPA), effect peak velocity (EPV) and duration of the EL CENTRO record (NS) of 1940 are

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338cm/s/s, 45cm/s, 10.88cm, 290cm/s/s, 30.77cm/s and 9.3s respectively, which only rank as 81, 87, 49, 99, 62 and 58 in a database that consists of more than five thousand significant strong ground motions records collected over the world. Evidently, whether the records should be considered as the severed design ground motions is a problem that ought to be further thought over.

The concept of the severest design ground motions is presented in the paper. A recently developed comprehensive method for estimating damage potential of ground motions (ZHAI and XIE [4]) is used in selecting the severest design ground motions. The severest design ground motions corresponding to different site condition and different period structure are attained. Finally, the severest design ground motions are verified by two examples.

CONCEPT OF THE SEVEREST DESIGN GROUND MOTIONS

For the seismic design and structure analysis, especially for the great complex structure, one of the most important tasks is selecting the proper real ground motions for design. The severest design ground motions are the real ground motions that can drive the structure to its critical response and thereby result in the highest damage potential. Clearly, the severest design ground motions are concerned about some seismic environment, which includes the seismic severity and site condition where structures are located.

The literature on the severest design ground motions has not been found at home and abroad so far. Though in foreign country the study on this has been begun, the significant achievement has not been gained. Farzad Naeim etc.[2] selected out 1157 horizontal components (M larger than 5 and peak acceleration larger than 0.05g) from a database that consists of more than 5,000 significant strong ground motion records collected over the world from 1933 to 1992. Then they selected all horizontal components which ranked in the top 30 of 1157 components based on the instrumental parameters (Farzad Naeim [2]) except bracketed duration (PA, PV, PD, IV, ID) and basic spectral parameters (EPA and EPV). A set of 84 records was selected in this manner. Here IV is the abbreviation of maximum incremental velocity ID is the abbreviation of maximum incremental displacement. Next they complemented this selection with a subset of 36 records, which exhibited only significant strong motion duration. Thus, a database of 120 records was formed. The design ground motions have not been presented the severest design ground motions, but a lot of important fundamental information for the formation of design ground motion concept and selection of design ground motion was offered. The 120 records selected by Naeim were not been classified according to the site conditions. And the information of sit condition of the 120 records was not offered. So it is difficult for these records to be used for practice.

The main purpose of this paper has two. First, the concept of design ground motions is presented. Second, the design ground motions are gained by recently developed comprehensive method from a database that consists of more than five thousand significant strong ground motion records collected over the world.

DATABASE FOR SELECTING THE SEVEREST DESIGN GROUND MOTIONS

With classifying the records that we collected into Chinese records and foreign records, the severest design ground motions in this paper is determined.

Based on the 120 records selected by Naeim, 52 uniformly processed records with specific site condition are selected. Next another 4 records with ground-level recorded in Northridge earthquake of 1994 are complemented. Thus, a database of 56 abroad records used by this paper was formed. After that, 36 Chinese records (PA larger than 80gal) with specific site condition are selected from the strong ground motions database of Institute of Engineering Mechanics(IEM), Seismological Bureau of China. The 36 Chinese records are used by the paper.

The two databases have following characteristic: (1) No matter which damage potential to be scaled, the abroad database which consists of 56 records should be on top rank. Likewise, the 36 Chinese records have similar characteristic in the strong ground motion records database collected at home till 2001. (2) The records of two databases are all uniformly processed and ranked in term of all kinds of damage potential parameters. (3) All of these records have comparatively reliable site conditions.

CRITERION OF SELECTING THE DESIGN SEVEREST GROUND MOTIONS

A recently developed comprehensive method (ZHAI and XIE [4]) for estimating damage potential of ground motions is used in selecting the severest design ground motions in this paper. (1) First, .the records are ranked respectively in term of all kinds of parameters (PA, PV, PD, EPA, EPV, Duration, IV, ID and spectral intensities) which can reflect the damage potential of strong ground motions. Then the top rank records form the preparing selection databases of severest design ground motions. The databases are the Chinese database and the foreign database mentioned above. (2) The preparing selection databases of severest design ground motions are ranked again for further comparing. Based on the dual failure criteria of displacement ductility and plastic cumulative damage, displacement ductility and hysteretic energy that stands for the plastic cumulative damage to structure are used to character the severity of ground motions. The records with highest values of displacement ductility and hysteretic energy are selected from the preparing selection databases of severest design ground motions. And the site condition, natural period of structure and regulation of codes are considered. Then the severest design ground motions with different site condition and different structure period are gained.

In the process of selecting the severest design ground motions, various parameters are comprehensively considered, such as PA, PV, PD, EPV, energy duration, displacement ductility and hysteretic energy etc.. With considering comprehensively all kinds of strong ground motion parameters (the parameters directly measured directly from ground motion of its own and the parameters depending on the elastic and inelastic response) and various seismic damage criterions, the parameters used here are gained. Thus the event that various parameters can character the damage potential of strong ground motions in some conditions is admitted. Moreover, the event that these parameters will not character well the damage potential of strong ground motions in other conditions is also admitted. And the comprehensive method can fully involve the effects of the intensity, frequency content and duration of ground motions and the dynamic characteristic of structure.

The event of selecting the severest design ground motions from so many ground motions is a very complicated process, because it is affected by many factors. For instance, the severest design ground motions corresponding to different ground motion parameters and different structure parameters (period, damp, ductility, hysteretic model) may be different. It is impossible to select one kind of severest design ground motions for each possible parameters combination. But it must consider the effect of this difference in selecting the severest design ground motions. The effect of various factors is considered when ranking again the preparing selection databases of severest design ground motions. Here several basic concepts are presented, after that the effect of various factors is analyzed.

Several basic concepts

(1) Displacement ductility

$$\mu = v_{\max} / v_y \tag{1}$$

where μ is the displacement ductility, $v_{\max}$ maximum displacement of inelastic system, v_y the yield displacement of system.

(2) Yield strength coefficient (or yield resistance seismic coefficient)

$$c_y = \frac{F_y}{mg} \tag{2}$$

where F_y is the strength of the system£¬ mg the effect weight of the system.

(3) Hysteretic energy

The hysteretic energy is gained by subtracting the elastic strain energy $\frac{1}{2k}[f(t)]^2$ from total strain energy $\int_0^t f(t)dv$:

$$E_p(t) = \int_0^t f(t)dv - \frac{1}{2k}[f(t)]^2 \tag{3}$$

where E_p is the hysteretic energy, $f(t)$ restoring force, k stiffness of system, v relative displacement.

(4) Equivalent velocity of hysteretic energy (Masayoshi N et. al.[1])

$$E_p = \frac{1}{2} M V_p^2 \tag{4}$$

where M is the mass of system, V_p equivalent velocity of hysteretic energy.

Factors considered in comparing the damage potential of ground motion with displacement ductility and hysteretic energy

Based on the dual seismic damage criterion of displacement ductility and cumulative damage, study (ZHAI and XIE [4]) shows the combination of the displacement ductility and hysteretic energy that characters cumulative damage to structure can reliably denote the damage of strong ground motions to structure when the seismic response of the structure enters its inelastic phase. When calculating displacement ductility and hysteretic energy, the following assumptions are made.

Basic assumption

As the characteristics of real structure under the seismic action are particularly different, the hysteretic models are various, which include bilinear model, tri-linear model and Clough model etc. The bilinear model has the characteristic of simple form and calculating conveniently, and it can reflect natural character of the seismic response. The bilinear model is used widely and it is the basic model for studying seismic response of inelastic structure. So bilinear model is assumed in calculating displacement ductility and hysteretic energy. Besides, the factors influencing displacement ductility and hysteretic energy are characteristics of structure, such as period, damping, yield resistance seismic coefficient, displacement ductility and the values of stiffness after yielding etc.. As showing in Table 1, two earthquake records are selected as input to analyze the influence factors. The records selected are intended to cover at least two types of ground motions, namely: (1) Near-field, short duration, impulsive type ground motion, as B2 record; and (2) far-field, long duration, relatively severe and symmetric type cyclic excitati0n, as B1 record.

Table 1 Data of two records

No.	Time	Earthquake	Recording station and component	Magnitude (M_L)	Epicentral distance (KM)
B1	1940	El Centro	El Centro-lmp Vall lrr Dist, N00E	7.7	12
B2	1966	Parkfield	Cholame Shandon Array 2, N65E	5.6	6

The conditions (constant ductility or constant strength) of comparing displacement ductility and hysteretic energy of different ground motions

In seismic response analysis, the dynamic parameters of structure mainly include four, namely: damp, displacement ductility (or yield resistance seismic coefficient), hysteretic model and structure period. To hysteretic energy, if hysteretic model (bilinear model assumed in this paper) is given, the parameters of structure that define ground motion hysteretic energy will be period of structure T, viscous damping ratio ξ and displacement ductility μ(constant ductility spectra) or period of structure T, viscous damping ratio ξ and yield resistance seismic coefficient C_y (constant strength spectra). Thus, the hysteretic energy of SDOF system under the earthquake can be expressed as following:

$$S= S(D, T, \xi, \mu) \text{ or } S=S(D, T, \xi, C_y) \quad (5)$$

where S is hysteretic energy, D is the hysteretic model.

In comparing the damage potential of different strong ground motions with hysteretic energy, generally there are two ways: under constant ductility condition or under constant strength to compare the damage potential of different strong ground motions. Two ways are identical in theory. But which way is more convenient? Figure 1 and Figure 2 show the hysteretic spectra of constant strength (C_y= 0.05, 0.10, 0.20, 0.40) and hysteretic spectra of constant ductility (μ=2.0, 3.0, 4.0, 5.0). In the figures, T and V_P correspond to the period of structure and the equivalent velocity of hysteretic energy. It can be observed that, hysteretic spectra of constant strength have any regularity and the variance of it is very large. But the regularity of hysteretic spectra of constant ductility is better and the variance of it is small. So comparing the damage potential of different ground motions is performed with the hysteretic spectra of constant ductility.

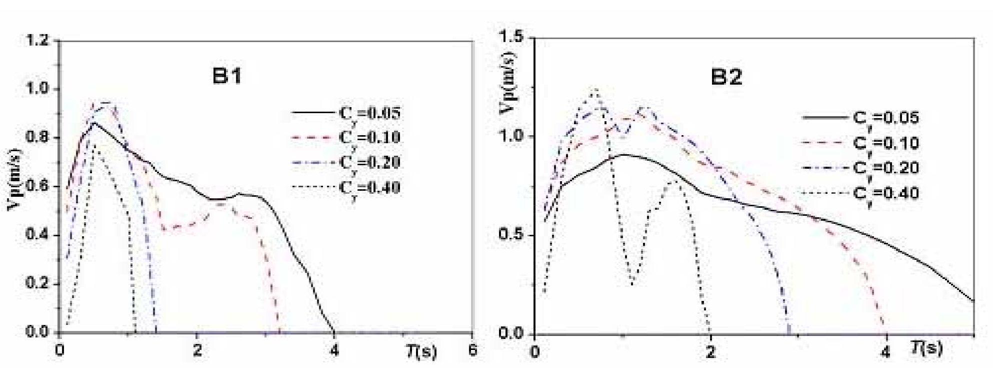


Figure1. Hysteretic spectra of constant strength

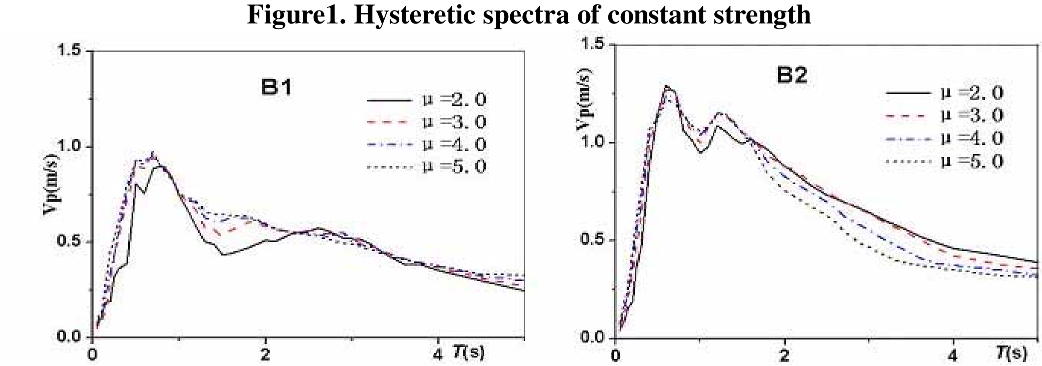


Figure2. Hysteretic spectra of constant ductility

In comparing the damage potential of different strong ground motions with displacement ductility, like comparing with hysteretic energy, there are two ways: (1) comparing the displacement ductility of structure under the condition of constant strength, and (2) comparing the yield resistance seismic coefficient demanded by structure in case of constant ductility. Two ways are identical. As yield resistance seismic coefficient of structure increasing, the seismic response decrease and therefore the displacement ductility decrease. On the other hand, as yield resistance seismic coefficient of structure decreasing, the seismic response increase and therefore the displacement ductility increase. For a given yield resistance seismic coefficient of structure, there is a displacement ductility corresponding to it, inversely, it is the same. So comparing the displacement ductility of structure in case of constant strength and comparing the yield resistance seismic coefficient demanded by structure in case of constant displacement ductility are same. But in order to keep consistent with the hysteretic energy, comparing the yield resistance seismic coefficient demanded by structure in case of constant displacement ductility performs the seismic damage criterion of displacement ductility. In a word, the event of selecting the severest design ground motions with displacement ductility and hysteretic energy is embodied by comparing the yield resistance seismic coefficient and hysteretic energy demanded by different structure in case of constant displacement ductility, same damping and hysteretic model.

Influence structure parameters on strong ground motion hysteretic energy

(1) Influence of hysteretic model (mainly referred to the second stiffness of bilinear model)

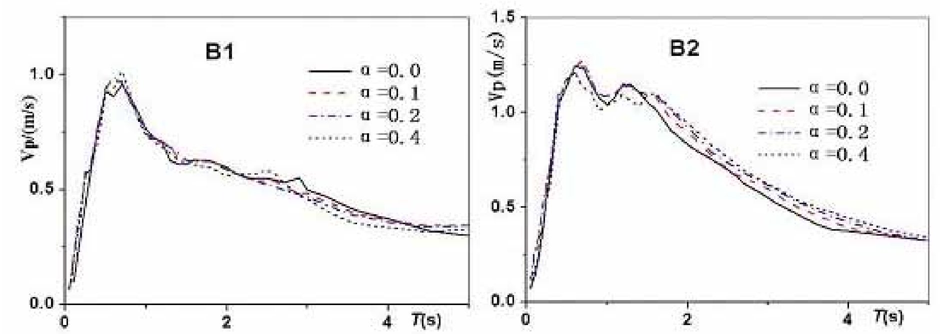


Figure 3. Influence of hysteretic model (mainly referred to the second stiffness of bilinear model) on hysteretic energy (μ=4)

The influence of second stiffness of bilinear model on hysteretic energy is shown in Figure 3, where α is the ratio of second stiffness to the first stiffness. The range of α is from 0.0 to o.4 and when α equal to 0.0, the bilinear model will become elastic-perfectly plastic model. It can be observed that the hysteretic energy spectra are generally insensitive to the values of the second stiffness of bilinear model. The range of hysteretic energy spectra peak value keeps within 10% of the peak value for the given range of α. Thus, the assumption of elastic-perfectly plastic model is relatively small for the result.

(2) Influence of displacement ductility

Figure 2 shows the hysteretic energy spectra of displacement ductility (μ=2, 3, 4, 5). The figure indicates that hysteretic energy spectra are generally insensitive to the level of displacement ductility. The range of the hysteretic energy spectra peak value keeps within 10% of the peak value for the given displacement ductility range. So, only one level of displacement ductility is considered in selecting the severest design ground motions.

(3) Influence of damping

The influence of damping (damping ratio ξ=0.02, 0.05, 0.10) on hysteretic energy is shown in Figure 4, where displacement ductility equal to 4. From the figure, we can see viscous damping affects hysteretic energy a great deal; a larger viscous damping gives a smaller hysteretic energy. The difference of hysteretic energy spectra peak value will reach 20-30% with damping ratio equaling to 0.02 and 0.10. It is can be observed that the trend of hysteretic energy spectra for different damping is nearly same. The damping ratio 5% of structure is assumed in this paper.

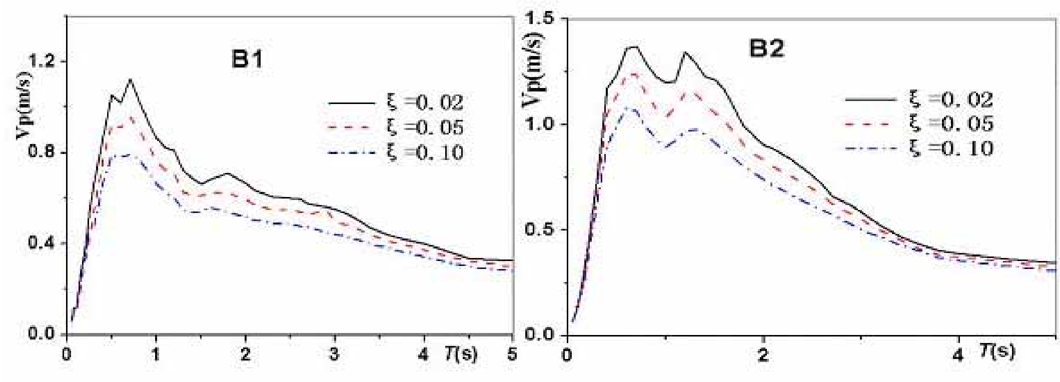
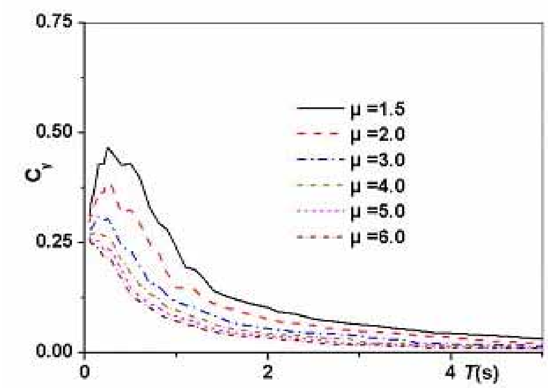


Figure 4. Influence of damping on hysteretic energy(μ=4)

(4) Influence of structure period

The yield resistance seismic coefficient and hysteretic energy demanded by structure in case of constant displacement ductility have relation with structure period. During different structure period range, the value of the yield resistance seismic coefficient and hysteretic energy may be different. Based on studying a great deal inelastic response spectra and energy spectra, we find that constant ductility spectra and hysteretic energy spectra during the short period range (0-0.5s), middle period range (0.5-1.5s) and long period range (1.5-5.5s) will keep a relative steady form. So in this paper the structure periods are divided into three parts: short period range (0-0.5s), middle period range (0.5-1.5s) and long period range (1.5-5.5s). The severest design ground motions corresponding to different site condition and different period ranges of are selected respectively. Figure 5 and Figure 6 show the mean constant ductility spectra and mean hysteretic energy spectra of 56 records collected in foreign country. The figures prove that the shape of constant ductility spectra and hysteretic spectra keep a relative steady form during the three period ranges mentioned above.



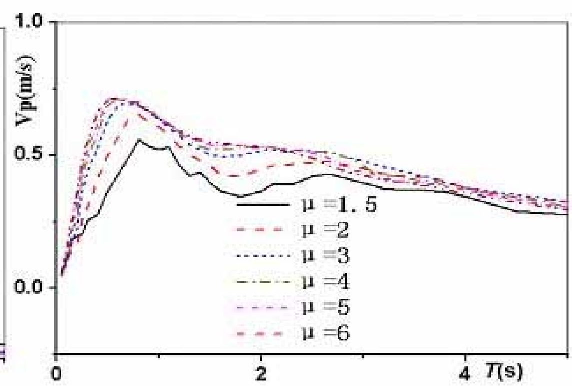


Figure 5. Mean constant ductility spectra **Figure 6. Mean hysteretic energy spectra**

Influence of site conditions and peak value of acceleration

The real ground motion site condition should be consistent with the site of structure in practice, likewise, the peak acceleration of ground motion should equal to the values of codes. So in selecting the severest ground motions, it should be selected for different site conditions and the real ground motions should be scaled to design acceleration specified by code. In this paper, the acceleration of real ground motions are normalized to the same level before comparing the damage potential of different ground motion with its parameters.

PROCESS OF SELECTING THE SEVEREST DESIGN GROUND MOTIONS

First, the structure periods are divided into three parts: short period range (0-0.5s), middle period range (0.5-1.5s) and long period range (1.5-5.5s), and the site condition of ground motion is classified into four classifications (I, II, III, IV) in term of code (GB0011 - 2001). Next, the yield resistance seismic

Table 2 The severest design ground motions of site I, II, III, IV

Site condition	Short-period structure input (0.0—0.5s)			Middle-period structure input (0.5—1.5s)			long-period structure input (1.5—5.5s)		
	Group Num.	Record name	Comp.	Group Num.	Record name	Comp.	Group Num.	Record name	Comp.
I	F1	1985,LaUnion, Michoacan Mexico	N90E★ N00E★ Vert	F1	1985,La Union, Michoacan Mexico	N90E N00E★ Vert	F1	1985,La Union, Michoacan Mexico	N90E N00E★ Vert
	F2	1994,Los Angeles Griffith Observation, Northridge	360★ 270 Vert	F2	1994,Los Angeles Griffith Observation, Northridge	360★ 270 Vert	F2	1994,Los Angeles Griffith Observation, Northridge	360★ 270 Vert
	N1	1988,Zhutang A, Langcang	S00E★ S90E Vert	N1	1988,Zhutang A, Langcang	S00E★ S90E Vert	N1	1988,Zhutang A, Langcang,	S00E★ S90E Vert
II	F3	1971,Castaic Oldbridge Route, San Fernando	N69W★ N21E Vert	F4	1979,El Centro, Array #10, Imperial Valley	N69W★ N21E Vert	F4	1979,El Centro, Array #10, Imperial Valley	N69W★ N21E Vert
	F4	1979,El Centro, Array #10, Imperial Valley	N69W★ N21E Vert	F5	1952,Taft, Kern County	N21E★ N69W Vert	F5	1952,Taft, Kern County	N21E★ N69W Vert
	N2	1988,Gengma, Gengma1	S00E★ S90E Vert	N2	1988,Gengma, Gengma1	S00E★ S90E Vert	N2	988,Gengma, Gengma1	S00E★ S90E Vert
III	F6	1984,Coyote Lake Dam, Morgan Hill	285★ 195 Vert	F7	1940,El Centro-lmp Vall lrr Dist, El Centro	180 270★ Vert	F7	940,El Centro-lmp Vall lrr Dist, El Centro	180 270★ Vert
	F7	1940,El Centrolmp Vall lrr Dist, El Centro	180 270★ Vert	F12	1966,Cholame Shandon Array 2, Parkfield	N65E★ # Vert	F5	1952,Taft, Kern County	N21E★ N69W Vert
	N3	1988,Gengma, Gengma2	S00E★ S90E Vert	N3	1988,Gengma, Gengma2	S00E★ S90E Vert	N3	988,Gengma, Gengma2	S00E★ S90E Vert
IV	F8	1949, Olympia Hwy Test Lab, Western Washington	356★ 86 Vert	F8	1949, Olympia Hwy Test Lab, Western Washington	356★ 86 Vert	F8	1949, Olympia Hwy Test Lab, Western Washington	356★ 86 Vert
	F9	1981,Westmor and , Westmoreland	90★ 0 Vert	F10	1984,Parkfield Fault Zone 14, Coalinga	90★ 0 Vert	F11	1979,El Centro Array #6, Imperial Valley	230★ 140 Vert
	N4	1976,Tianjing Hospital, Tangshan	WE★ SN Vert	N4	1976,Tianjing Hospital, Tangshan	WE★ SN★ Vert	N4	1976,Tianjing Hospital, Tangshan	WE★ SN Vert

Note：①Symbol“ ★” denotes the severest design ground motions selected by this paper.
②Symbol“ F” denotes foreign records and symbol“ N” denote domestic records。
③Symbol“ #” denotes the components that have not been found.

coefficient and hysteretic energy demanded by structure under different ground motions (in case of constant ductility) are calculated. According to the values of the yield resistance seismic coefficient and hysteretic energy the final ranks of ground motion corresponding to different cases are gained. Because of the space limitation, the details of ground motions are presented in literature (Zhai [3]). Finally, according to the ranks of yield resistance seismic coefficient and hysteretic energy demanded by structure under different ground motions, the top rank two foreign records and top rank one record in Chinese preparing selection database are selected as the severest design ground motions (total 18 records). Here if two records are two components of one ground motion, the two records are considered as one. And the three records should be collected in different earthquake and different site station. Fifteen groups of severest design ground motions (eleven foreign groups and four Chinese groups) are presented by complementing the corresponding other components. The severest design ground motions corresponding different site conditions and different structure periods are shown in Table 2.

Here it should be noted, the Chinese severest ground motions in this paper are severest only for Chinese ground motions not for foreign ground motions. As the quantity of Chinese strong ground motions is very small, especially for the near-field strong ground motions, the Chinese severest ground motions are far from the severest in the world.

EXAMPLES

The severest design ground motions are verified by comparing the seismic response of structure under the severest design ground motions and the commonly used ground motions.

Example 1

The Zhengda-Square of Fuzhou is located in the center of Fuzhou. The main building is a high-rise building with reinforced concrete and shear walls. Its height is 162 m. The inelastic seismic response program of DRAIN-2D is used in this example. The seismic inelastic response time history of the building is performed under the major earthquake of Fuzhou. The first period and second period of structure are 2.6944s and 0.7325s.

Four strong ground motions are selected for input, among which three strong ground motions are provided by site design ground motion parameters report of Zhenda project in Fuzhou, the fourth is the severest design ground motions recommended by this paper. The peak acceleration corresponding to major earthquake is normalized to 230gal. The four ground motions are followed.

1) Man-made ground motion
2) El Centro (NS) of 1940 ground motion
3) Holister of 1961 ground motion
4) El Centro (WE) of 1940 ground motion

Under the four ground motions mentioned above, the displacement of the main building top story is gained. The absolute maximum displacement and maximum displacement angle of the peak point are listed in Table 3. It can be observed that the response of structure under the severest design ground motions recommended by this paper is larger than that under the commonly used ground motions.

Table 3 Absolute maximum displacement and maximum displacement angle of the peak point

	Ground motion used commonly			The severest design ground motions recommended
	Man-made ground motion	El Centro (NS) of 1940	Hollister	El Centro (WE) of 1940
Absolute maximum displacement (m)	0.283	0.224	0.162	0.402
Maximum displacement angle	1/570	1/720	1/996	1/398

Example 2

New city mansion of Tokyo is 48 stories above the ground and its height is 243 meters. The structure is a super steel structure system. The period of the structure is 5.234 second and its damping ratio is 0.02. The peak acceleration corresponding to major earthquake is normalized to 745gal. Nine strong ground motions are selected for input, among which two strong ground motions are the EL CENTRO record (NS) of 1940 and TAFT record of 1952, the other seven ground motions are the severest design ground motions recommended by this paper. The nine ground motions are followed.

1) El Centro (NS) of 1940 (shorten form is 40EL1)
2) Taft of 1952 (shorten form is Taft)
3) Gengma (S00E) of 1988 (shorten form is Gengma) (site condition is III)
4) El Centro (EW) of 1940 (shorten form is 40EL2) (site condition is III)
5) El Centro Array #10, Imperial Valley CA of1979 (shorten form is 79EL1) (site condition is II)

6) La Union, Michoacan Mexico of 1985(shorten form is Mex.) (site condition is I)
7) Los Angles, Griffith Observation, Northridge of 1994 (shorten form is Northridge) (site condition is I)
8) El Centro Array #6,Imperial Valley CA of 1979 (shorten form is 79EL2) (site condition is IV)
9) Olympia Hwy Test Lab, Western Washington of 1949 (shorten form is Olympia) (site condition is IV)

Under the nine ground motions mentioned above, the displacement of the structure top story and maximum story displacement are gained. The result is shown in Table 4. It can be observed that the response of structure under the severest design ground motions recommended by this paper is larger than that under the common used ground motions.

Table 4 Absolute maximum displacement of the peak point and the maximum story displacement

	Ground motion used commonly		The unfavorable design ground motions recommended						
			Site I		Site II	Site III		Site IV	
	40EL1	Taft	Mex	Northridge	79EL1	Gengma	40EL2	79El2	Olympia
Max, Displacement of peak point(m)	0.60	0.61	1.01	0.936	3.76	0.78	1.99	2.87	1.01
Max. story Displacement (m)	0.015	0.016	0.027	0.027	0.096	0.020	0.055	0.072	0.038

Short remarks

In the examples mentioned above, the seismic response of high-rise reinforced concrete structure and super steel structure is analyzed. It can be observed that the response of structures under the severest design ground motions recommended by this paper is from a little larger to several times than that under the common used ground motions. The validity and reliability of the severest deign ground motion are verified preliminary. Besides, the seismic response analysis of middle or low multistory brick structures and reticulated shells is performed in literature (Zhai [3]). The result is also relatively perfect.

CONCLUSIONS

The concept of the severest design ground motions is presented in the paper. A recently developed comprehensive method for estimating damage potential of ground motions is used in selecting the severest design ground motions. The severest design ground motions corresponding to four classifications of site condition and three period ranges of structure are attained. The three period ranges of structure are long period ranges (1.5-5.5s), middle period ranges (0.5-1.5s) and short period ranges (0.0-1.5s). At the end, the validity and reliability of the severest deign ground motions are verified preliminary by two examples. The severest design ground motions provide the input for seismic analysis and design of structures and they can be used directly in earthquake engineering research and practice.

In addition, from this paper it can be observed that the damage potential of the strong ground motions used widely in practice, like El Centro (NS) of 1940, is much low than that of some ground motions, like the severest design ground motions recommended in this paper.

It deserves to be noted that the severest design ground motions is a complex concept, which is not only concerned with the characteristic of ground motions, but also with the ground motion damage potential and structure damage mechanics. The severest design ground motions presented in this paper is a relative concept, namely, the severest design ground motions presented here are selected from strong ground motions in existence in case of some sit conditions, regarding the design peak acceleration of codes as the peak acceleration of real ground motion and only considering one horizontal component action. As further understanding to the ground motion damage potential and structure damage mechanics, the newly and more severe design ground motions will be found with the accumulation of strong ground motions.

ACKNOWLEDGE

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