13th World Conference on Earthquake Engineering
Vancouver, B.C., Canada
August 1-6, 2004
Paper No. 1509

DETERMINATION OF NONLINEAR DEMAND SPECTRUM FOR EVALUATION OF SEISMIC STRUCTRAL PERFORMANCE

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SUMMARY

At present, many studies on nonlinear spectrum have worked out, and many theoretical results are got. But how to evaluate the seismic structural performance using nonlinear spectrum, have not be solved all over the world. In this paper, the records all over the world are classified according to characters of spectrum and the criterion of site by code for seismic design of buildings (GB50011-2001)[1], the plastic demand spectra of every wave is calculated corresponding yield strength coefficient, and the mean plastic demand spectrum is established and simplified corresponding to deferent site. Seismic performance of structures under different level earthquakes (such as frequent, occasional and rare) is evaluated using the method of capacity spectrum.

INTRODUCTION

the nonlinear static analysis method is put forward by Freeman etc. in 1975. In the following years, more attentions are not paid. In the early 1990s, the methods of performance-based and displacement-based seismic design were put forward by scientists and engineers of the United States. The scholars of Japan and European are also interested in that and begin to study the method of Pushover again. It is accepted and absorbed gradually by the code for seismic design of some countries, such as ATC-40, FEMA-273&274, Japan and Korea etc. The code for seismic design of buildings (GB50011-2001, for short new code) states that "we should adopt the simplified Nonlinear Analysis method or Nonlinear history-time Analysis. ", and "the nonlinear static analysis and the nonlinear dynamic analysis are commended in this code" . The nonlinear static analysis here is just the method of Pushover.

The method of capacity spectrum is regarded as the development of the pushover method. In fact, seismic performance of structure can been evaluated according to structural base shear force, roof displacement and story drift at the performance point which is the intersection point between the seismic demand spectrum and the structural capacity spectrum. But several technical problems for the method are followed. The first one is how to obtain the plastic demand spectrum because the capacity spectrum of structures considers structural nonlinear behavior. In the paper, two methods as following are use to establish the plastic demand spectrum: 1) using plastic response spectrum of acceleration and

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This work was sponsored by National Natural Science Foundation of China under Grant NO.50008017.
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displacement directly; 2) considering elastic-plasticity indirectly by using equivalent damping. Because the first method is concerned with many uncertain factors (such as ductility factor, the factor of yield strength etc.), the second method is used widely in the world at present. Although the acceleration spectra according to different damping ratio are given in new code, the displacement spectra according to different damping ratio are not given. In the paper, two aspects will be discussed: 1) classifying earthquake records according to the criterion of site by new code; 2) establishing displacement response spectrum according to different damping ratio.

CLASSIFYING ACCORDING TO THE CRIERION OF SITE

There are four sites and each site has three groups in new code. The paper classifies the earthquake records into nine groups using character period of site (T_g), whose relative character period of site is 0.25, 0.30, 0.35, 0.40, 0.45, 0.55, 0.65, 0.75 and 0.90. Three parameters are presented in grouping, which are characteristic period of the earthquake record(T_g'), area of acceleration response spectrum and duration of the earthquake record. The rule of selecting earthquake waves is: 1) T_g' of waves is approaching to T_g of site; 2) the discrepancy between the area of acceleration response spectrum of earthquake record and that of standard response spectrum by new code not surpassing 15%; 3) the duration of earthquake not less than 30 seconds. The defining method of T_g' is shown in fig.1. According to the three parameters the paper classifies 2031 earthquake records all over the world records into nine groups, and the result of groups is shown in the table 1.

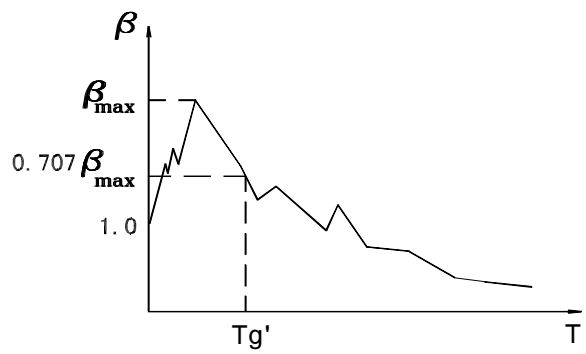


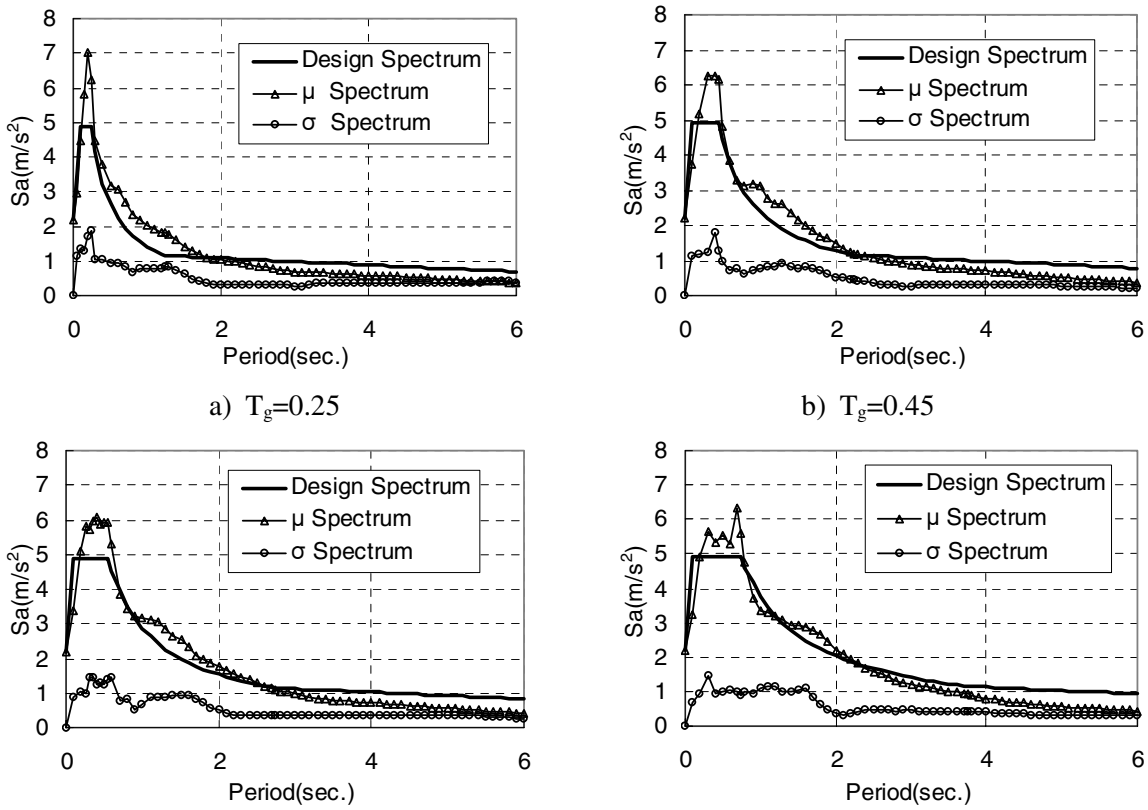
Fig.1 The defining method of T_g'

Table 1 Classification of earthquake records

T_g	0.25	0.30	0.35	0.40	0.45	0.55	0.65	0.75	0.90
Control range of T_g'	[0.2, 0.275]	[0.275, 0.325]	[0.325, 0.375]	[0.375, 0.425]	[0.425, 0. 50]	[0. 50, 0. 60]	[0. 60, 0. 70]	[0. 70, 0.775]	[0.775 0. 95]
Number of earthquake records	28	11	19	19	21	29	18	16	10

Fig.2 shows the average spectrum(μ) and standard variance spectrum(σ) of acceleration response spectra of earthquake records stated in table 1. The PGA is 220gal/s^2 and the damping ratio is 5%. In the paper, the response spectra of four sites are list.

As is shown in fig.2, the acceleration response spectra of elected earthquake records are satisfied with the standard response spectrum by new code in average significance. Fig.2 illustrates the principle that the standard variance of acceleration spectrum is rather larger in short period range, but smaller in the long period range.



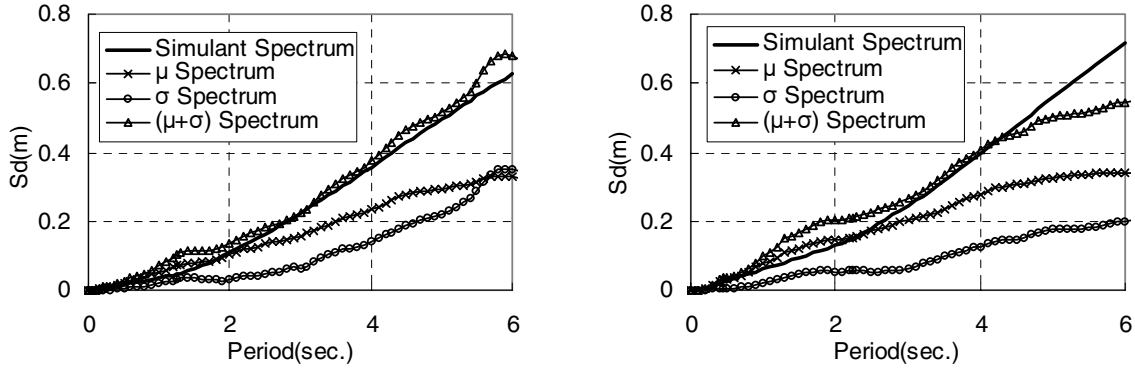
a) T_g=0.25 b) T_g=0.45

c) T_g=0.55 d) T_g=0.75

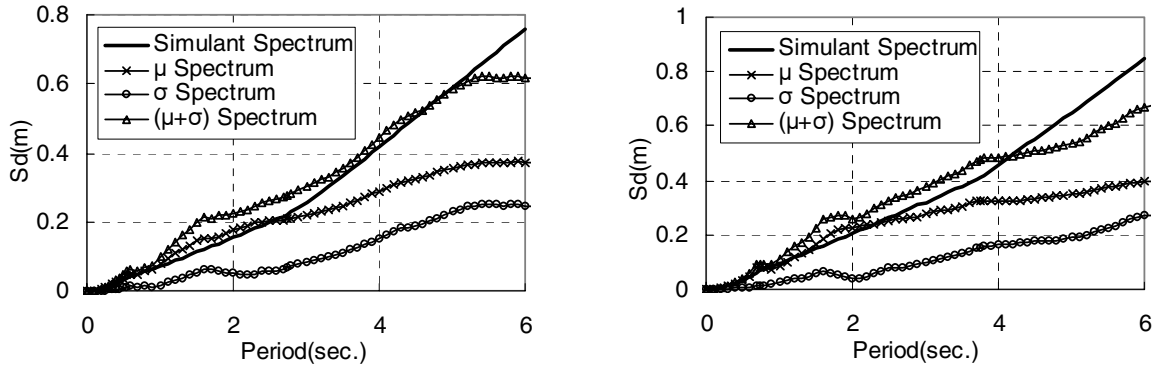
Fig.2 Acceleration response spectrum

THE CHARACTERISTICS OF DISPLACEMENT RESPONSE SPECTRUM

Fig.3 shows the average spectrum(μ), standard variance spectrum(σ) and the average plus one standard variance of the displacement response spectrum of earthquake records stated in table 1.



a) T_g=0.25 b) T_g=0.45



c) T_g=0.55 d) T_g=0.75

Fig.3 Displacement response spectrum

It is shown in fig.3 that the standard variance of displacement response spectrum is rather smaller in short period range, but larger in the long period range. The standard variance achieves half of average, even surpassing average in the same period. So it is difficult to evaluate the biggest displacement response of structure under earthquake and to represent variance extent by using average displacement response spectrum directly because of instruments' distortion effect of earthquake records in long period. However, there is approximate considerable reliability to use the (μ+σ)spectrum to simulate displacement response spectrum by new code. In the paper, a feasible method of using pseud-displacement response spectrum obtained by acceleration design response spectrum in new code is presented to determine demand spectrum of the structure whose period is within 6 seconds.

THE COMPARE OF THE METHOD OF CALCULATING INELASTIC DEMAND SPECTRUM

The important step is to establish inelastic demand spectrum of different level earthquakes using the method of capacity spectrum to evaluate the seismic performance of structures. There are two methods to calculate inelastic demand spectrum. The inelastic demand spectrum is calculated by the structural factors of yield strength ξ_y and yield stiffness p in the first method. ξ_y is the ratio of the yield shear force to the maximal elastic force of structure, p is the ratio of the yield stiffness to the elastic stiffness of structure. According to the studies of Chopra[4], the inelastic demand spectrum is calculated by the equivalent damping ratio in the second method. As the structural factor of yield strength is known, the structural yield displacement, ductility factor and equivalent damping ratio can be calculated according to formula (1), (2) and (3). Because the yield displacement of each period of response spectrum is different, the ductility factor and equivalent damping ratio of each period of inelastic demand spectrum are also different. So the inelastic demand spectrum is calculated according to the actual damping ratio of each period in the paper. Fig.4 shows the average inelastic demand spectrum which is calculated by two methods under T_g=0.45, ξ_y=0.4 and 0.5, p=0.1.

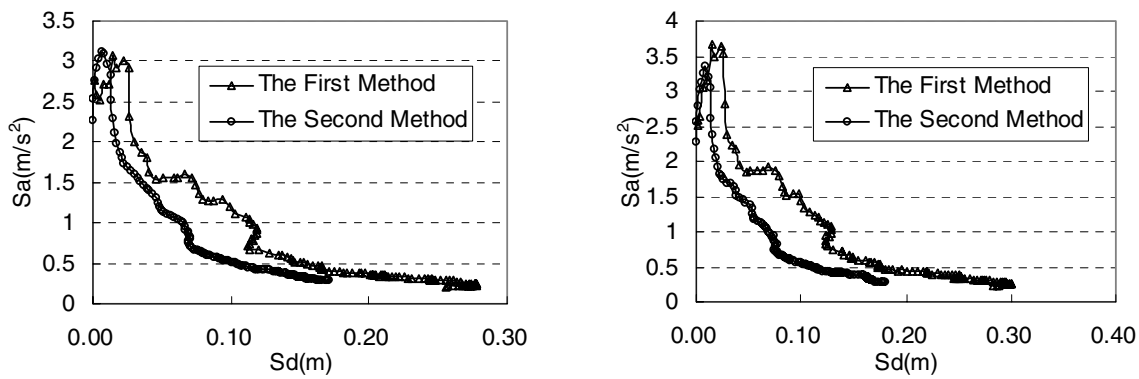
$$X_y = \xi_y \times X_{e\max} \tag{1}$$

$$\mu = \frac{X_{p\max}}{X_y} \tag{2}$$

$$\zeta = 0.05 + \frac{2(\mu-1)(1-p)}{\pi\mu(1+p\mu-p)} \tag{3}$$

Here, μ is ductility factor, $X_{p\max}$ is the inelastic maximal displacement opposite to ground under earthquake, $X_{e\max}$ is the elastic maximal displacement opposite to ground under earthquake, X_y is yield displacement, ζ is equivalent damping ratio.

In fig. 4, the great difference of the inelastic demand spectra is in middle and long period between the first method and the second method. the inelastic demand spectrum of second method is less than the one of the second method at equal period. The difference relates to the method of calculating equivalent damping ratio in the second method. To obtain the consistent demand spectra, the method of calculating equivalent damping ratio should be studied more.



a) ξ_y=0.4 b) ξ_y=0.5

Fig.4 Inelastic demand spectrum (T_g=0.45)

INELASTIC DEMAND SPECTRUM BASED ON NEW CODE

Plotting the earthquake demand spectrum and the capacity spectrum of structures together, the performance point is determined and the seismic performance of structures under different level earthquakes can been evaluated using the method of capacity spectrum. Because it is difficult for the engineers to use the nonlinear demand spectrum of actual earthquake waves in the actual practice, the inelastic earthquake demand spectrum can be substituted approximately by the design demand spectrum according to different damping ratios. Fig.5 shows the demand spectra of different damping ratios based on the new code and the capacity spectrum of a 12-story frame structure.

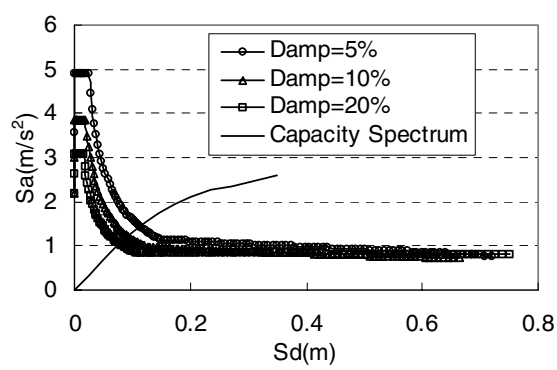


Fig.5 Capacity spectrum and demand spectra with different damping ratios (T_g=0.45)

CONCLUSIONS

Conclusions can be obtained according to the analysis of the paper,

(1) The acceleration response spectrum of selecting earthquake records is satisfied with the standard response spectrum by new code in average significance.

(2) There is approximate considerable reliability using the (μ+σ)spectrum to simulate pseudo-displacement response spectrum obtained by new code.

(3) By the contrast of two methods of establishing inelastic demand spectrum, the structural seismic performance under different level earthquakes can be evaluated by adopting the design demand spectra of different damping ratios based on the new code approximately in the actual practice. But the method of calculating equivalent damping ratio should be improved more.

ACKNOWLEDGEMENT

This work was sponsored by National Natural Science Foundation of China under Grant NO.50008017.

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