THE SPATIAL CONTINUOUS EARTHQUAKE DESIGN RESPONSE SPECTRA

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ABSTRACT :

Firstly, the fuzzy characteristics of site classifications were analyzed, the spatial distribution of two-dimensional membership function for 4 types of site was presented and the fuzzifying of the site classification was realized. Nextly, the continuous method of the site characteristic period and the two-dimensional graphs was provided; the result shows that the characteristic period distribution confirmed by this method corresponds with the equivalence chart of the characteristic period given in current earthquake resistance code. Finally, a continuity method of design response spectra is proposed based on continuous characteristic period and design response spectra. It's spatial distribution graphics are presented and the engineering application of continuous design response spectra are also discussed. Practice proves that the continuous design response spectra confirmed by this method realized the smooth transition of design response spectra corresponding to 4 types of site. It is more accordant with the reality of engineering sites which have the features of non-determinacy, fuzziness and variance. It also develops a new idea for consideration characteristic affections more reasonably, as well as determination seismic design response spectra and seismic action more objectively and scientifically.

KEYWORDS: architectural aseismic, design response spectra, characteristic period, spatial continuity method

1 INTRODUCTION

Taking a single-particle elastic structure possess certain damping as the target of study, seismic response spectra represents the relationship curve of the structural free vibration period and the maximize response of the ground motion caused by an earthquake. Seismic design response spectra are several typical statistical analysis curve of response spectra obtained from different seismic record on the same site. It can be expressed in the form of seismic effect coefficient curve in practical projects. Design response spectra are a rule to design the earthquake force in essence. Using of seismic response spectra theory (RST), it's convenient to transform dynamical design problem into static one for aseismic design of architectural structures. RST has been the basic theory. So, since M. A. Boit(1943) and G. M. Housner(1948) put forward the idea of response spectra and develop a response spectrum method, RST has gained wide acceptance among aseismic designers and has been applied extensively in the earthquake resistance code in the world.

The main factors that influence the response spectra include: focal mechanism, dissemination way, site condition, structural damping of a single-particle structure and its self-vibration characteristics. All of the above are taken into consideration the effect on design response spectra by seismic intensity, types of sites, design seismic group, structural free vibration period and damping parameters in the earthquake resistance code. To facilitate engineering anti-earthquake design, current earthquake resistance code (GB50011-2001. (2001)) was divided into three design seismic groups. Each group is composed of 4 types of standard sites (the interval of site characteristic period: T_g=0.25~0.90s). Discrete design response spectra curve are given under the action of the frequently or rarely met earthquake, among which T_g is one of the important parameter. Determining T_g objectively and scientifically is quite significant to determine the design response spectra rationally. The value of T_g in current earthquake resistance code depends on the type of sites and design seismic group. The latter determined by the new seismic motion zoning map. This paper will get the continuity characteristic period Tg, then to produce the continuity method of design response spectra on the basis of discussion the influence of the types of sites upon Tg (Design seismic group is constant).

2 SITE FUZZY CHARACTERISTICS AND FUZZY CLASSIFICATION

2.1 Fuzzy characteristics of site classification

Site soil has important influence on the seismic frequency spectrum characteristics (Hu Y.X, Sun P.Sh., Zhang Z.Y. and Tian Q.W.(1980)). Site classification is frequently used in engineering projects to characterize the variation in reaction of seism to site conditions. First of all, there are many complicated elements influencing site classification. But for a certain practical project, there are usually only limited indexes available to classify the site. In this case, therefore, even a definite classification index or a method tends to make the classification fuzzy. Second, the site soil, composed of solid, liquid and gas phases, manifests extremely complicated and ambiguous characteristics due to variation in proportion of the shapes of solid granules, the mineral element and sizes of granules. Third, the concept of site class lacks precision in intension and clearness of extension. All of the above indicates that site classification inevitably contains fuzzy characteristics. The fuzzy classification conforms to the sites classification essence, can reflect the realistic situation objectively.

2.2 Space distribution of site fuzzy classification based on two-dimensional membership function

The engineering sites are classified into four major types according to the cut wave speed (v_{se}) and the covering layer thickness (d_{ov}) in the current earthquake resistance Code(GB50011-2001. (2001)). The two-dimensional membership function to fuzzify the 4 types of site are established in paper(Zhang, S.H., Liu, S.J., Ou, J.P. and Wang, G.Y..(2005).)(see expresses 1 to 4 in paper 3).Four space distribution diagrams of two-dimensional membership function can be seen in Fig. 1. In which, $\mu_j(d_{ov},v_{se})$ is the membership function of the jth ($j\in[1,4]$) class standard site ,v_{se} and d_{ov} can be ascertained with the method prescribed in Code(GB50011-2001. (2001))and Code (GB/T50269-97. (1998).).The membership function of site classification above has the following characteristics:1)It realizes the fuzziness of site classification.2)It takes into consideration the fuzzy characteristics of site soil and its classification.3)It expresses the complex non-linear relationships between the classification indexes and the site classes. It makes full use of the classification result and conception of current earthquake resistance Code(GB50011-2001. (2001)) and Code (GB50191-93. (1994).).To do the site classification on this basis, we can expect more objective results.

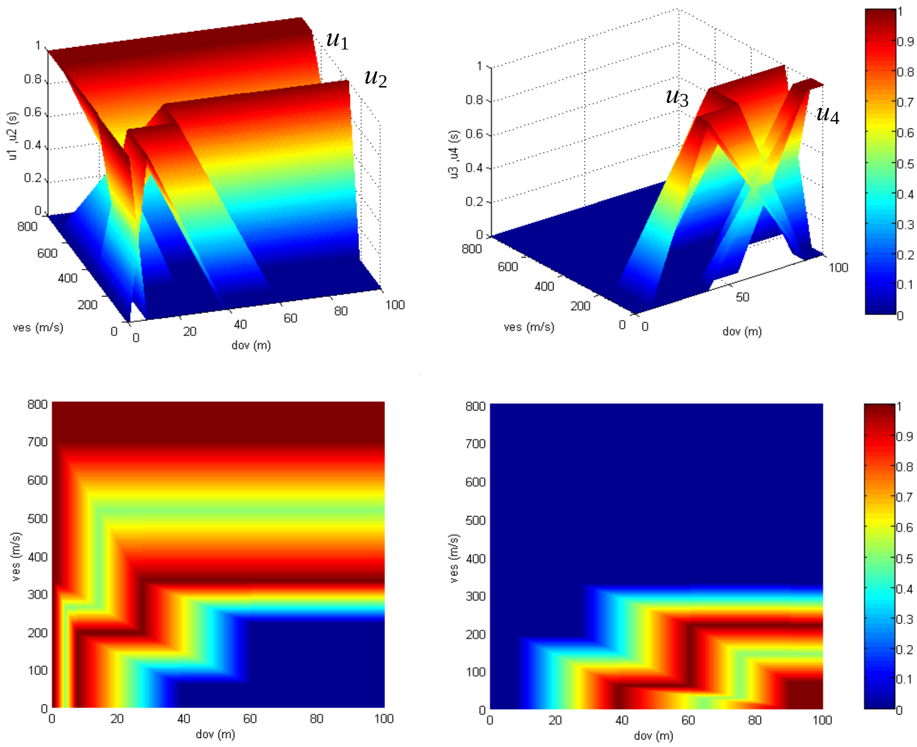


Fig.1 The two-dimensional membership function about the four classes of site fuzzy classification

3 CONTINUITY METHOD OF SITE CHARACTERISTIC PERIOD AND SEISMIC DESIGN RESPONSE SPECTRA

3.1 Continuity of Characteristic Period

The influence of the site on the response spectra is considered in the form of site characteristic period in the current earthquake resistance Code(GB50011-2001. (2001)). In order to be consistent with Code(GB50011-2001. (2001)) and to make full use of information of the membership vector $\mu=\{\mu_j(d_{ov},v_{se})\}_4$ and characteristic period of site fuzzy classification, we shall establish continuity of characteristic period and achieve the continuity of the seismic reaction spectrum.

μ_j expresses the membership degree of a certain site to the j^{th} class of standard site. Likewise, this membership degree or the unified degree expresses as well the importance or relatively importance of the j^{th} class site characteristic period in the actual characteristics period of a certain site. Then, the unified membership degree being weight, we may confirm, about i^{th} design seismic group, the site continuity characteristics period expression T_{gi}(see express (3.1)).In which the value of the j^{th} site class of design seismic group i is T_{gij}($T_{gij}\in T_{GB}=\{T_{gij}\}_{3\times4}$),which can be confirmed through site characteristics period table (see Table (1)) according to Code(GB50011-2001. (2001)).

$$T_{gi}=\sum_{j=1}^{4}\mu_j T_{gij}\Big/\sum_{j=1}^{4}\mu_j \tag{3.1}$$

Table1 Characteristics Period$\{T_{gij}\}_{3\times4}$ (s)

Design Seismic Group	Types of Sites			
	I	II	III	IV
Group 1	0.25	0.35	0.45	0.65
Group 2	0.30	0.40	0.55	0.75
Group 3	0.35	0.45	0.65	0.90

Note: The value of characteristic period should increase 0.05s under the action of rarely met earthquake (the earthquake intensity is 8 degrees or 9 degrees).

3.2 Space Distribution of Characteristics Period

The Space distribution of the site continuity characteristics period for the seismic group i($i\in[1,3]$) was confirmed through express(3.1). Where, we fulfill the ergodic operation in the value interval in d_{ov} and v_{es},and we determine corresponding membership degree vector $\mu=\{\mu_j(d_{ov},v_{se})\}_4$ of four types of standard sites.Chart of characteristic period distribution for the third type of design seismic group can be seen in Fig.2. Obviously, T_{g3} has the better spatial continuity and corresponds with the equivalence chart of the characteristic period given in current earthquake resistance Code(GB50011-2001. (2001)). So, the characteristics period introduced in this paper can be used directly in the calculation of various earthquake resistant structures.

3.3 Design Response Spectra of Standard Sites

Calculating the function of the structure against seism is the basic of anti-quake architectural structure design. It is also one of the key issues in the implementation the requirements for fortification against earthquakes. Response spectrum theory still is the foundational theory of seismic design in many countries now. Design response spectrum is one of the main bases of seismic calculating. The design response spectra adopted in the code are shown in graphics of earthquake effect factors. Fortification intensity, site classification, design seismic group, structural free vibration period and damping parameters are major factors in determining the earthquake effect factor. In our current earthquake resistance Code(GB50011-2001. (2001)),the standard design response spectra $a_{ij}(T_{gij},T)$($i\in[1,3]$, $j\in[1,4]$) are given under the action of the frequently or rarely met earthquake, among which the code was divided into three design seismic groups. Each group is composed of 4 types of standard sites. The curve of earthquake effect factor a(T) for standard site is shown in Fig.3. Four kind of standard design response spectrum curves $a_{3j}(T_{g3j},T)$ of the third design earthquake group(the earthquake intensity is 8 degrees, it is under the action of the frequently met earthquake, concrete structure) can be seen in

Fig. 4. The maximum values of earthquake effect factor under the action of the frequently or rarely met earthquake are presented in Table 2.

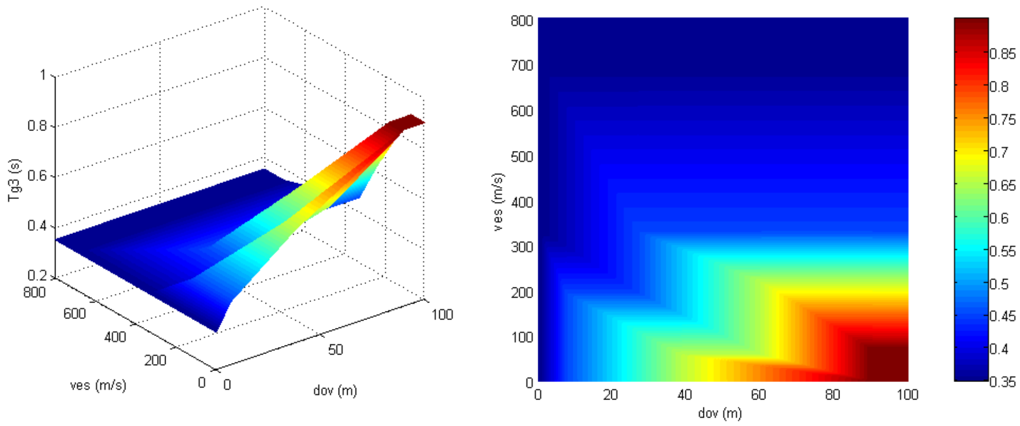


Fig.2 Chart of characteristic period continuation for the third type of design earthquake

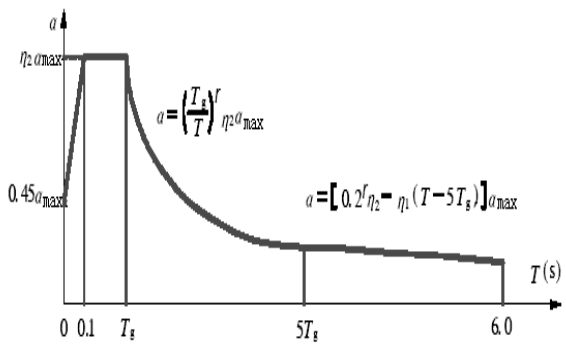


Fig.3 Curve of earthquake effect factor

Note: a-earthquake effect factor;
a_{max}-Maximum values of earthquake effect factor;
T-structural free vibration period;
T_g-characteristic period; γ -attenuation index;
η_1-descending slope regulation factor;
η_2-damping regulation factor

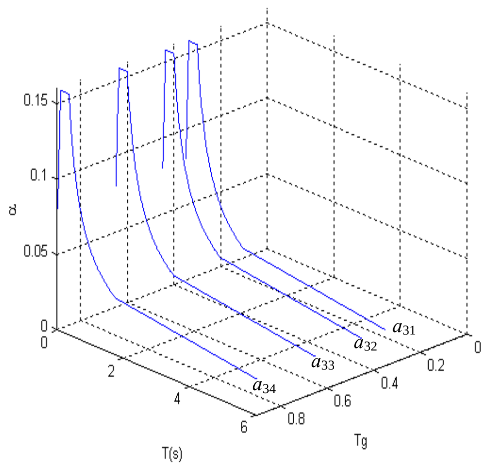


Fig.4 Four kind of standard design response spectrum curves a_{3j} of the third design earthquake group(the earthquake intensity is 8 degrees, it is under the action of the frequently met earthquake, concrete structure)

Table 2. Maximum values of horizontal earthquake effect factor a_{max}

earthquake effect	6 degree	7 degree	8 degree	9 degree
Frequently met earthquake	0.04	0.08(0.12)	0.16(0.24)	0.32
rarely met earthquake	--	0.50(0.72)	0.90(1.20)	1.40

Note: Value in parenthesis is used for design the regions which basic seismic acceleration is 0.15g or 0.30g.

3.4 *Continuity Method of Design Response Spectra*

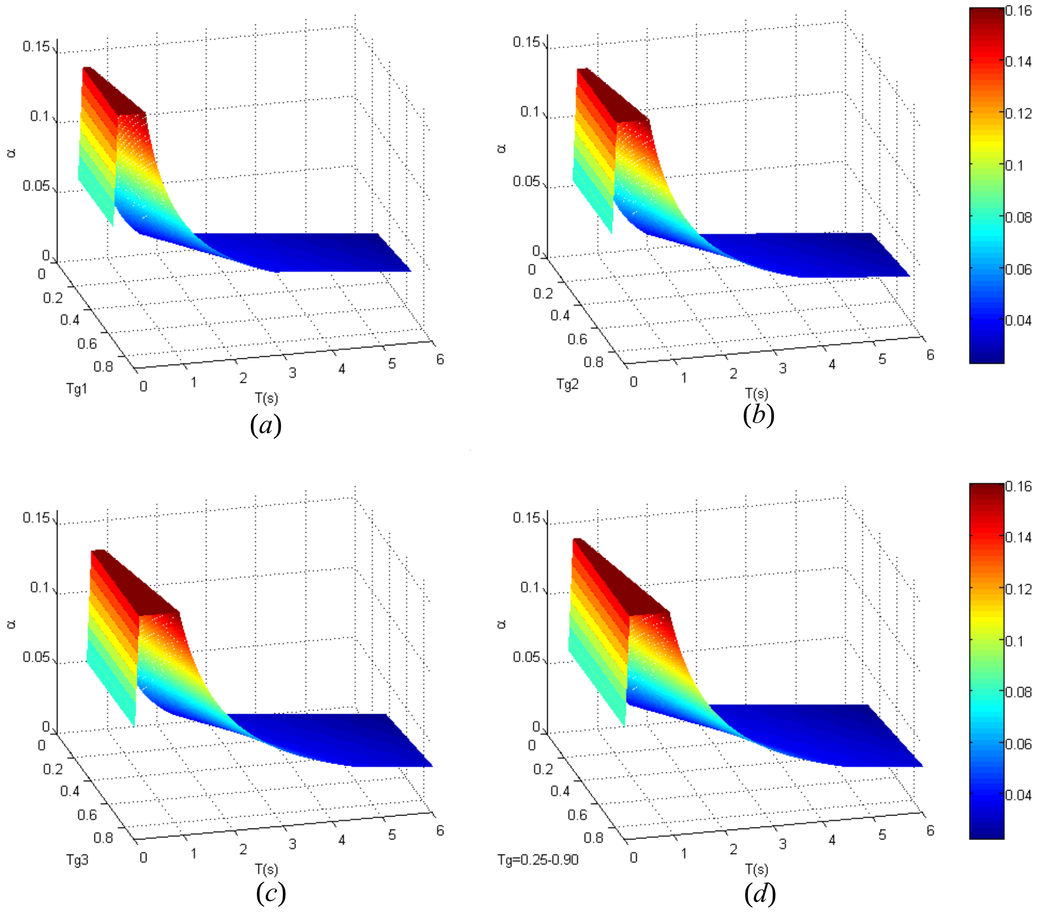
From express (1), the site continuity characteristics period T_{gi}, about i^{th} design seismic group can be confirmed. Some information of four standard sites, like membership degree and characteristic period typical value etc are considered. So the T_{gi} can express characteristics period of sites reasonably, objectively and continuously. One can plug T_{gi}($i\in\{1,2,3\}$) separately into earthquake effect factor curve a(T) (see Fig.3),then a continuous seismic reflection curve $a_i(T)$ corresponding to three design seismic groups ($i\in\{1,2,3\}$) can be obtained. The influence of design seismic grouping and fuzziness of site are given much consideration in this curve, so it has laid the foundation of determining the earthquake action of aseismic construction more objectively and reasonably.

3.5 ***Space Distribution of Design Response Spectra***

We fulfill the ergodic operation in the value interval in T_{gi} and structural free vibration period T, and we can determine the space distribution of three continuous seismic reflection curve $a_i(T)$.The space distribution of design response spectra for three design seismic groups(the earthquake intensity is 8 degrees, it is under the action of the frequently met earthquake, concrete structure) can be seen in Fig. 5(a~c).The synthetic space distribution of design response spectra is shown in Fig.5(d).

3.6 ***The Engineering Application of Continuous Design Response Spectra***

First, we can obtain the membership degree vector ($\mu=\{\mu_j(d_{ov},v_{se})\}_4$) of site fuzzy classification for the ith design seismic group of one practical engineering j according to d_{ov} and v_{se} (see Fig.1); Then we can obtain the site characteristic period T_{gij} of the ith design seismic group for site j according to express (1); Using T_{gij} in $a_i(T_{gi},T)$ we can also obtain response spectra formula $a_i(T_{gij},T)$; Based on the design response spectra we can calculate and check further for the seismic action more objective.



(a) The first design seismic group (Tg1=0.25-0.65 s) (b) The second design seismic group (Tg2=0.30-0.75 s)
(c) The third design seismic group (Tg3=0.35-0.90 s) (d) synthetic space distribution (Tg=0.25-0.90 s)

Fig.5 spatial distribution of design response spectra
(the earthquake intensity is 8 degrees, it is under the action of the frequently met earthquake, a_{max}=0.16)

4 CONCLUSIONS

Firstly, we analyzed the site fuzzy characteristics and proposed the spatial distribution of two-dimensional membership function for four types of standard site based on current seismic code; Fuzzy classification of site is realized and it offers the most likely solutions to recognize site fuzzy characteristic and classify site objectively. Nextly, based on the two-dimensional membership function and characteristics periods of different design seismic group, continuity method of site characteristic period is proposed and its spatial distribution graph is put forward; it provides the ground for determining site characteristics periods more reasonably. Thirdly, on the basis of continuous characteristic period and site design response spectra we establish a continuity method of designing response spectra. The spatial distribution of design response spectra corresponding to three design seismic groups is given; Continuity design response spectra realized the transition of design response spectra corresponding to four types of standard sites. It can reflect the fact of site objectively with the features of complexity, fuzziness, and variability. It has proposed the new train of thought and method for the consideration the influence of actual site features more reasonably, as well as determining seismic design response spectra and earthquake action more scientifically. Finally, the engineering application of continuity design response spectra is discussed.

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