THE EFFECT ANALYSIS OF TOPOGRAPHY ON THE SPECTRUM PROPERTY OF GROUND MOTION

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ABSTRACT :

This paper presents results of numerical analyses for the seismic response of uniform visco-elastic site under different vertically propagating seismic waves including SH waves、SV waves and P waves. The aim of this paper is to explore the effects of site geometry, dynamic properties of soil or rock, as well as predominant excitation frequency on seismic ground motion. A step-like slope model and a mesa model are established and an explicit finite difference method is performed to evaluate the significance of topography effects. Two-dimensional finite-element analyses are conducted using artificial bell-shape impulse wavelets and recorded bedrock motions as base excitation. Moreover, effects of slope inclination、the incident direction and characteristic size of step-like slope on the spectrum property of the incoming waves are all discussed in detail. The conclusions show that the presence of topographic factors and the direction of the incident waves not only significantly affect the peak ground acceleration of sites, but also affect the spectrum property of the incoming waves, and the effect of direction of the incident waves is especially remarkable. The study also finds that it is reasonable to analysis spectrum properties with the input of impulse wavelets in the finite element simulation of wave motion. Furthermore, the spectrum ratio defined in this paper can be more effectively used to extract the pure effect of topographic irregularities compared with transfer function which is also widely adopted.

KEYWORDS: visco-elastic site explicit finite difference method finite element simulation of wave motion topography effect

1.INTRODUCTION

Seismic response of topographic irregularities has drawn so much attention in the field of earthquake engineering. Methods used to solve this kind of problems can be generally reduced to analytical solution and numerical simulation. Among the published studies, while analytical solutions presented, the local topography always can be expressed with a simple function, Such as two-dimensional canyon and vally, （Trifunac，1971；Wong et al.，1974；Liu et al.，1990）、hemispherical canyon and circular-arc alluvial valley（Lee et al.，1982；Liang Jianwen et al.，2003）. These solutions always focused on specific sites with regular boundary and uniform material properties, linear-elastic for example. As to nonuniform、nonlinear material and sites with irregular boundaries, analytical solutions become too complicated to present. However, these complexities give numerical simulation enough space to develop, with better applicability for topographic irregularities. Commonly, In order to get seismic response through numerical simulation, a proper 2D(Boore ，1973；Geli，1988; Yang Baipo et al.，1992；Li Xiaojun et al.，1995；D.Assimaki，2004) or 3D（Chen Binwu et al.，1982；Sanchez-Sesma，1990）computing model is established at first, then different seismic excitation at the base of the model could introduced as a time history of acceleration (or velocity, or displacement) in the form of impulse or real earthquake movement, sometimes, numerical simulation solutions can be verified by record field evidence (D.Assimaki，G.Gazetas 2004). After a literature reviewing, we have known much about topographic effect on peak ground acceleration, but referring to the effect of topography on the spectrum property, it is still obscure to great extent. And it has drawn the least attention among scientists. Aiming at this goal of exploring local topography effect on spectrum property, results are presented from a parametric study of step-like slope, performed with the explicit finite difference method introduced by Lixiaojun（Li Xiaojun et al.，1993）. Our study focuses merely on the case of propagating SH、SV and P waves.

2. METHODOLOGY OUTLINE AND VERIFICATION

The numerical analyses were performed with the explicit finite difference method (Li Xiaojun, Liao Zhenpeng etc, 1995), which have good accuracy and could effectively overcome the enlargement of calculating high frequency error via the introducing of a new numerical integration format. More specifically, several calculating illustration are as follows:

- quadrilateral zones were used to simulate the uniform soil or rock mass
- damping effect is taken into account with the form of Rayleigh damping, [C]=α[M]+β[K], [C]、[M]、[K] separately presents damping matrix、mass matrix and stiffness matrix
- the space discrete step of finite element mesh is set at less than (1/10)λ_T (λ_T is the wave length of base excitation whose cycle is T) in order to make sure the calculating precision while the wave propagating in the discrete system
- transmitting boundaries were applied at the base、right and left sides of the mesh.

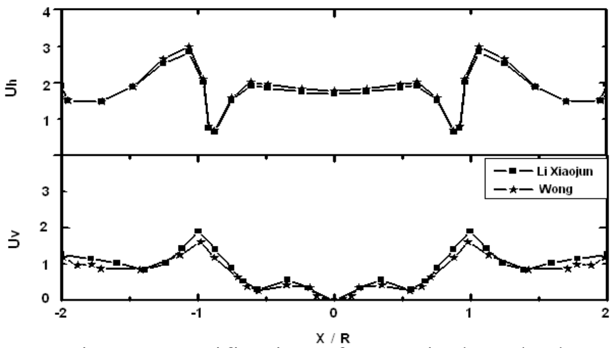

Figure 1 Verification of numerical method
(vertical SV wave, R=25m, λ/R=2)

The overall accuracy of the numerical methodology was verified through comparison with analytical solutions for the seismic response of the ground surface across semi-circular shaped canyons, for uniform soil and vertically propagating harmonic SV waves. We choose this case because the analytical solutions got by Wong H L (1982) are commonly used for calibration of new methods (George D. Bouckovalas, Achilleas G. Papadimitriou，2005). Horizontal (Uh) and vertical (Uv) peak ground displacement are shown in Fig.1. From Fig.1 we knew the results got from explicit finite difference method can accord with analytical solutions preferably.

3. RECORDED FIELD EVIDENCE

During the 4 February 1975 M_L 7.3 Haicheng Earthquake, four aftershocks were recorded by observation sites set at the top and foot of Haicheng hill. The hill height is about 10m and NS dimension is larger than EW dimension. Two instruments are installed on the bedrock. According to site description, with thin surface sediment, the whole hill can be considered as two-dimensional granite mass. The major aftershock has provided 2 empirical spectrum ratio curves plotted in Fig.2. Also plotted in Fig.2. is the numerically computed spectrum ratio curve via impulse base excitation (Fig.4). It can be readily seen that the recorded and computed results are in reasonable agreement, offering support to the conclusions of the present section, as well as to the use of impulse as a valuable guidance in microzonation studies.

4. TWO SIMPLE MODELS AND IMPULSE

Step-like slope is common but typical. 9 observation points are listed in Fig.3. A schematic illustration of the 2D analyzed mesh and the boundary conditions is also provided in Fig.3. More specifically, Vs=1000m/s. Artificial transmitting boundaries were applied at the base of the mesh and at right and left sides, the width and the height of the mesh were set at 2000m and 400m. Quadrilateral zones were used to simulate the uniform material, with a maximum height of 5m, for time-domain parametric study, computing step interval was set at 0.001s.
Mesa model is also common and referred in the Code for seismic design of building. Its illus- -tration is

provided in Fig.4. Vs is set at 500m/s, H and L values change in the study, other physical conditions are the same as that of slope model.

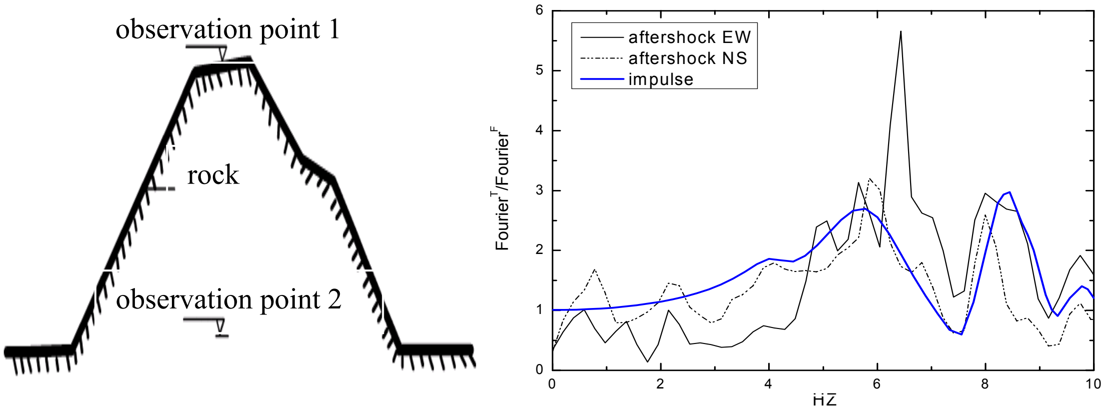

Figure 2 Haicheng hill and spectrum ratio comparison between recorded datum and calculating result via impulse excitation

In the finite-element simulation of near field, different bedrock excitations are adopted. We can use recorded bedrock motions or artificial bedrock motions or impulse wavelets. Impulse wavelets are widely used in this paper because our research focuses on the topographic effect, and the impulse wavelet input not only offer better results but also save much time of computing. Recorded bedrock motions always include a wide span of frequency content. Catering for this property, many kinds of impulse with simple shape and wider frequency content（about 0～30Hz） are considered.

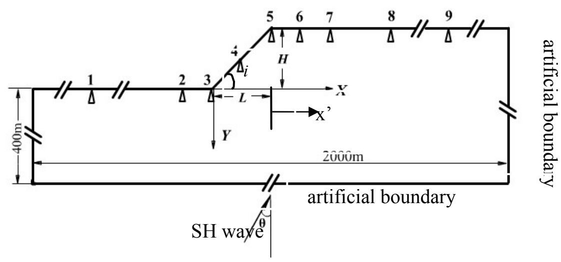

Figure 3 Model 1: step-like slope model （θdenotes angle of excitation）

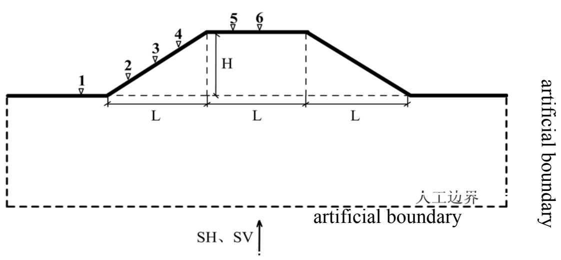

Figure 4 Model 2: mesa model

At last, bell-shape impulse wavelet is adopted. Its time history and fourier spectrum are illustrated in Fig.5. For convenience of dealing with data and suitability of using results, non-dimensionalization of frequency content of input time history is necessary. So f_c is introduced to measure the relation between characteristic size of slope and wavelength of incidence. $f_c = (L/2\pi\ c_s)\omega = L/\lambda_s$. The parameter U used to denote extent of topography effect is defined as the ratio of the fourier amplitude spectrum of the motion at observation point to the free-field motion.$U=|G(\omega,x)/G_0(\omega)|$, $G(\omega,x)$ presents fourier amplitude spectrum of observation point，$G_0(\omega)$ presents fourier amplitude spectrum of free-field motion.

In order to describe topography effect extent, transfer function is always used, but we found transfer function will mix up the effect of topography and effect of material damping. Take transfer function of the 7th observation point under the conditions of varying β and site without topography（H=0 i.e. half space） which is illustrated in Fig.6 for example, High frequency contents of seismic response of observation points are obviously diminished, which shows significant effect of damping on transfer function. This phenomenon is not hard to understand: for visco-elastic material, existence of damping makes the energy of earthquake waves gradually dissipate. Material damping is adopted as the form of Rayleigh damping（$\alpha=0$, $\beta\neq0$），energy dissipation increases while frequency of propagating waves augment. But, for some sites with topography effect, it is necessary to extract topography effect separately. So, spectrum ratio is introduced instead of transfer function. Spectrum ratio of the 7th observation point under the conditions of varying β and site without topography（H=0 i.e. half space） is illustrated in Fig.7. the result shows that spectrum ratio is 1 and the error beneath 5%, that is to say the dissipation of high frequency content is basically neglectable while using spectrum ratio.

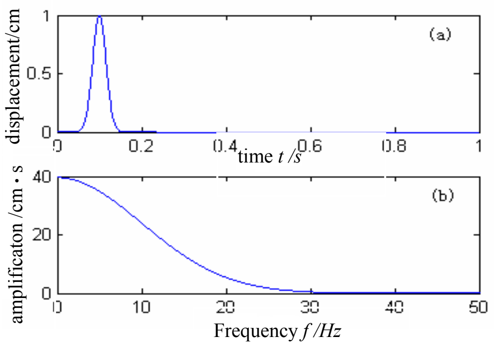

Figure 5 Displacement impulse（a）and its fourier spectrum(b)

5. PARAMETRIC STUDY OF SLOPE MODEL

Fig.8 present results from the parametric analyses demonstrating the effects of slope angle i, it is observed that the slope angle i have a significant effect on the aggravation of ground motions, as well as on the distance to the free field in front and behind the slope. a denotes peak ground motion of observation points, a_{ff} denotes acceleration of free field in front and behind the slope. While inclination angle less than 45°, with the increase of inclination angle, acceleration amplification of crest and acceleration reduction of toe become more obvious. While inclination approaches 70°, these orderliness changes and the maximal acceleration ratio appears at observation points near the toe and crest. But the largest acceleration amplification is less than 1.5.

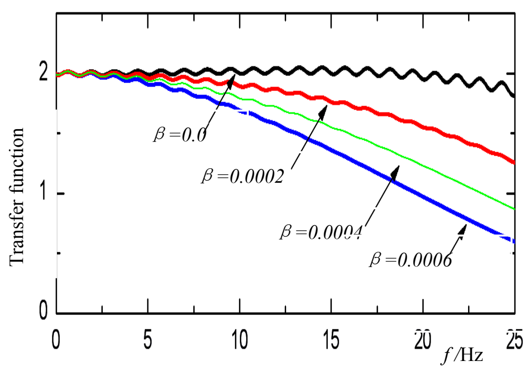

Figure 6 Transfer function of point 7under different damping coefficient β

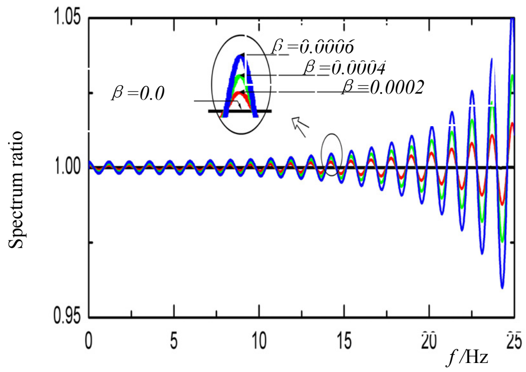

Figure 7 Spectrum ratio of point 7 under different damping coefficietβ

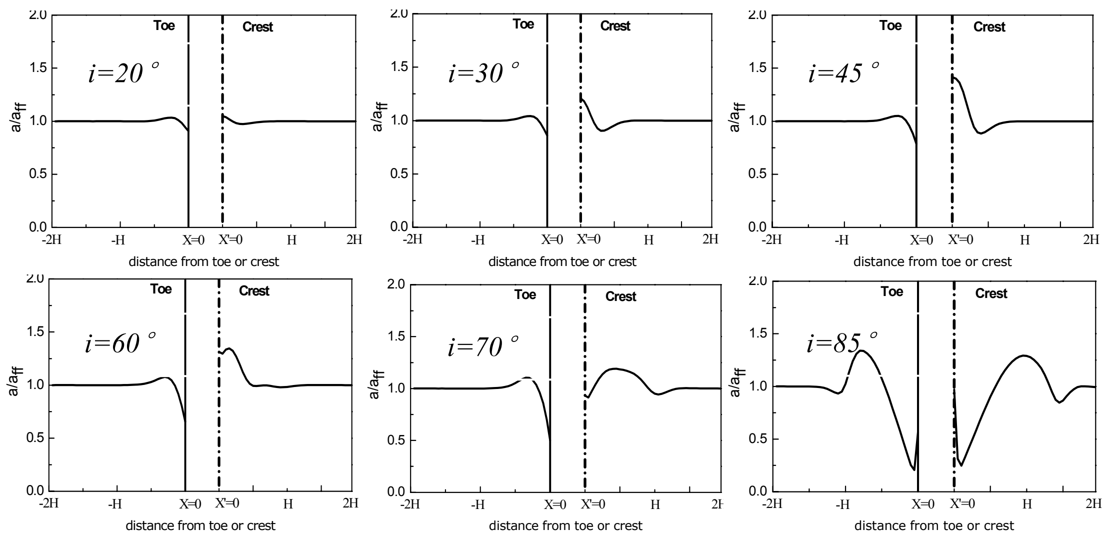

Figure 8 Effect of slope inclination i on PGA under vertical basic SH impulse excitation (slope height keeps 20m)

In order to show the effect of characteristic size on earthquake spectrum property, spectrum ratio of some representative observation points are illustrated in Fig.9.

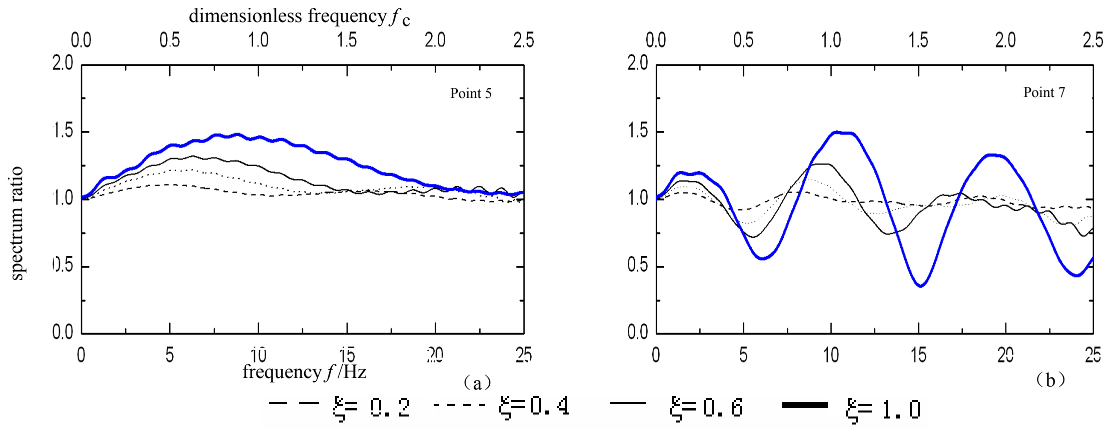

Figure 9 Effect of different ξ on local topography spectrum ratio(β=0.0002)

After analyzing the seismic response curve under different ratio of height to width, some conclusions can get from the results:A line whose Y-coordinate equals 1 in spectrum ratio chart is defined as the division of amplification and de-amplification, the larger of ratio of height to width, i.e. the larger of amplitude of spectrum ratio. If the ratio of height to width equals 0, site without topography reduce to half space. Spectrum ratio equals 1 theoretically no matter what frequency of excitation and no matter what the angle of incidence is. With the increasing of the ratio of height to width, spectrum ratio curve moves forward high frequency part. For 7th point (Fig.9（b）), predominant frequency of spectrum ratio curve moves from 9Hz to 11Hz and dimensionless predominant frequency is about 1. Increasing of the ratio of height to width complicated the shape of the spectrum ratio curve, and correspondingly makes the scope of amplificatory frequency becomes wider. From quantificational point, maximal spectrum ratio is less than 1.6 even the ξ=1. In order to show the effect of angle of incidence on earthquake spectrum property, spectrum ratio of some representative observation points are illustrated in Fig.10.we can get some conclusions from the results:

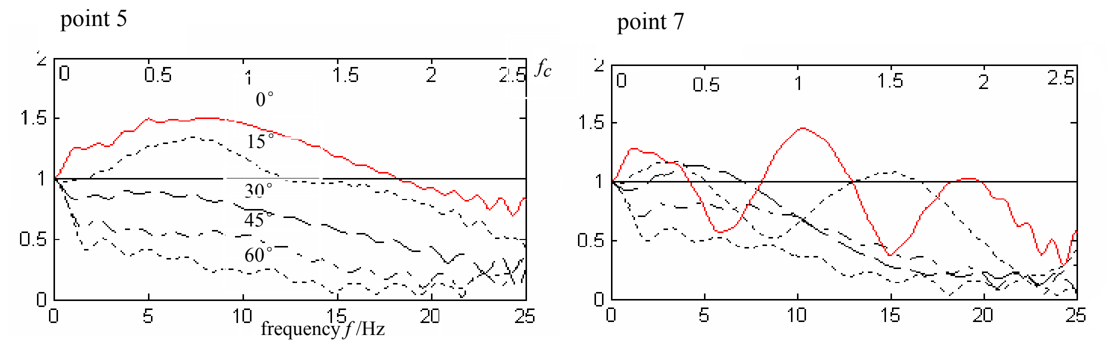

Figure 10 Effect of different θ on local topography spectrum ratio(β=0.0005)

For points on the crest, increasing of the angle of incidence makes the trend of amplification cut down and makes the span of amplificatory frequency becomes smaller. Take point 5 and 7 for example, for θ=0°, amplificatory frequency is 0～17Hz; for θ=15°amplificatory frequency is 0～13Hz;while θ>45°, amplification effect disappears. Maximal spectrum ratio appears under vertical incidence. The maximal spectrum ratio is less than 1.6.

Changes of β obviously affect the shape of spectrum ratio illustrated in Fig.11 for visco-elastic sites. In Fig.11, β varies from 0 to 0.0006, but spectrum ratio curve of the 7th observation point almost unaltered, it approves that spectrum ratio method could extract topographic factor effectively especially at lower frequency span of 0~7Hz. With the increasing of β, peak value of spectrum ratio diminished while the frequency varies from 7 to 25Hz. Summarily, resemblance of spectrum ratio curve explains that spectrum ratio method is well and truly to get trend of topograph- -ic effect on spectrum properties of earthquake ground motions.

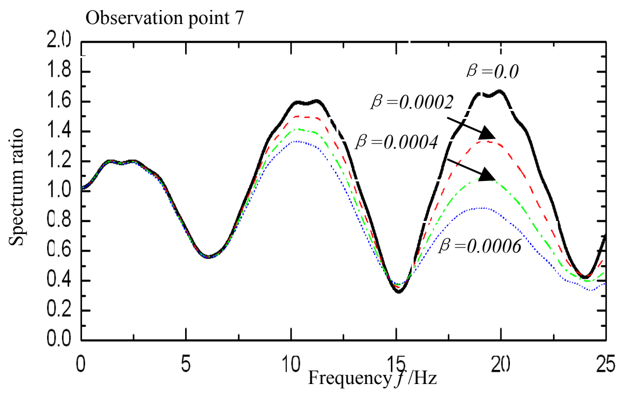

Figure 11 Effect of damping coefficient on spectrum ratio

6. PARAMETRIC STUDY OF MESA MODEL

For mesa model, we focus our attention on topography effect on characteristic period, as character- -istic period generally presents spectrum property of ground motion. Aiming at this goal, many earthquake samplings with presented statistic characters should provided at first, for example, earthquakes with the same peak ground acceleration or characteristic period. As we all known, there have not enough recorded datum, so, we must use artificial seismic waves. In this paper, design response spectrum in the code for seismic design of buildings is taken as target response spectrum and trigonometric series method is applied to compose introduce earthquake timehistories needed for earthquake response analysis, while used as basic excitation, their amplitude reduced a half. Refers to target response spectrum, T0 is set as 0.1s, T_g is set separately as 0.25s、0.3s、0.4s、0.5s、0.7s、1.0s, peak acceleration value is set as 200gal, damping ratio is 0.05, dynamic amplifying coefficient is set as 2.5, 6 different target response spectrum are presented. Time step interval and time steps are set as 0.02s and 2048. considering phase randomicity, three timehistories with different phasic randomicity are composed for each instance. There are overall 18 bedrock timehistories and they could basically reflect spectrum property difference of bedrock timehistories. In all, many parametric analyses were performed and study instances were showed in Tab.1.

Tab.1 parameter conditions for parametric analyses

H/L	H							β	(H=30m,H/L=0.5)					
									Tg(incidence)					
	10m	20m	30m	40m	50m	60m	70m		0.25	0.3	0.4	0.5	0.7	1
0.2			※			※								
0.3	※	※	※	※	※	※	※	0.0001		※		※		※
0.5	※	※	※	※	※	※	※	0.0002	※	※	※	※	※	※
0.8			※			※		0.0004	※	※	※	※	※	※
1			※			※		0.0006		※		※		※

※ means this situation is taken into account

For example, we take three artificial seismic waves with characteristic period 0.5s and peak acceleration 100gal as input waves, the damping ratio is 0.0002. Then site response calculation is conducted under the condition of the same average side slope degrade and increasing slope height. Earthquake responses of six observation points are gotton. After that, average response spectrum of three random response timehistories of each observation point is obtained and demarcated to get its characteristic period.

From Fig.12, it is obviouse that, while the slope height changes from 10 meters to 70 meters, characteristic period of the sixth observation point keeps the same value and they are all 0.1 second longer than that of input waves. Other observation points can get the same results, it explains that the change of slope height have tiny effect on characteristic period of ground motion. Fig.13-15 also present selected results from the parametric analysis demonstrating the effects of average side slope degradation、damping ratio、characteristic period of input waves. It is observed that, for visco-elastic ground with topography effect, characteristic periods of observation points are larger than that of incidence, the increscent amount is diminished with the increasing of characteristic period of incidence. The slope height、side slope degradation、material damping ratio have tiny effect on characteristic period of ground, it mainly depends on and commonly a little bigger(about 0.1s) than characteristic period of incidence. However, while the characteristic perild of incidence approaches 1.0s, this kind of period accretion becomes neglectable.

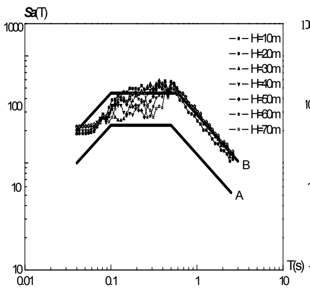

Figure 12 Effect of slope height on the characteristic period of ground motion (H/L=0.5,β=0.0002, Tg=0.5s)

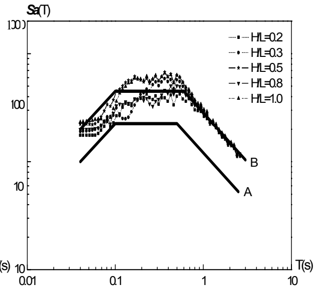

Figure 13 Effect of slope degradation on the characteristic period of ground motion (H=30m, β=0.0002,Tg=0.5s)

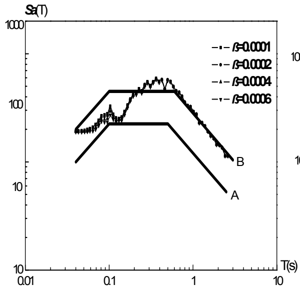

Figure 14 effect of damping ratio on the characteristic period of ground motion (H/L=0.5, H=30m, Tg=0.5s)

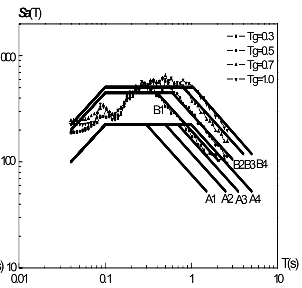

Figure 15 Effect of characteristic period of incidence on that of ground motion (H/L=0.5, β=0.0002, H=60m)

7. CONCLUSIONS

Explicit finite difference method is used to get Numerical solutions of specific visco-elastic sites. An extensive parametric study has been conducted for the geometry of the step-like slope and mesa. From the results, we know more about the effect of topography on the spectrum property. Mainly conclusions are as follows:

1) Under the condition of incident SH waves, the larger the value of ξ, U_{max} correspondingly becomes larger. The shape of the spectrum ratio moves forward high frequency. With the increasing of angle of incidence, amplification of crest gradually diminished, maximal spectrum ratio occurs under vertical incidence, the value of maximal spectrum ratio is less than 1.6.

2) The slope height、side slope degradation、material damping ratio have tiny effect on characteristic period of ground. It mainly depends on the characteristic period of incidence.

These conclusions could offer some references when we meet sites similar with calculating model. However, sites varies, and many influential factors such as 3D property、multi-topography are out of consideration, so specific analysis is necessary.

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