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A PROCEDURE FOR RATING SITE WITH CONSIDERING THE COMBINATION EFFECT OF SOIL LAYERS

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ABSTRACT

A procedure for rating site condition is presented in this paper. The Artificial Neural Network approach is adopted in the procedure to establish relationship between design response spectrum parameters and site condition variables. Totally 235 strong ground motion response spectra and the soil data at 85 sites where the motions were recorded were collected to construct the input and output samples for the network. To evaluate the suggested procedure, RMS deviation of 235 actual spectra to the network outputs is calculated, and it is also compared the value with those from the procedures in the existing building aseismic design codes.

KEYWORDS

Site rate, design response spectrum, soil layer combination, Artificial neural network

INTRODUCTION

As well known, site condition plays a key role in determination of design response spectra. In general, sites are classified into various categories according to the soil depths and the mean shear wave velocities. In this way, the same design spectra are going to be assigned to two sites which have the same depths and mean velocities, in spite of the shear wave velocities in each corresponding pair of layers are quite different. Many lessons learned from destructive earthquakes have shown that ground responses at two sites could be very different even due to a same shock, at same epicenter distance, and the same average indexes, if those sites have obvious different columnar sections. A lot of site earthquake response analyses have also brought light to significance of the combination effect of soil layers. For example, Earthquake performances of two sites shown in the next page must be different. The Vs in the profiles means shear wave velocity in meters per second. The asesismic stability of the profile (b) is much better than that of (a), because there is a stable bearing soil layer in the upper part of profile (b) and a soft layer in the lower part which will dissipate energy of shear wave. From point of view of vibration propagation, ground motion intensity at site (a) will be stronger than that at site (b) under the same rockbed motion input, and the spectral amplitudes at long period range will also be larger than those at site(b). Similarly, for a stiff site with a thin soft intercalation, the motion intensity will decrease with the intercalation varying with depth from the surface, while the spectral amplitudes at long period range will increase relatively.

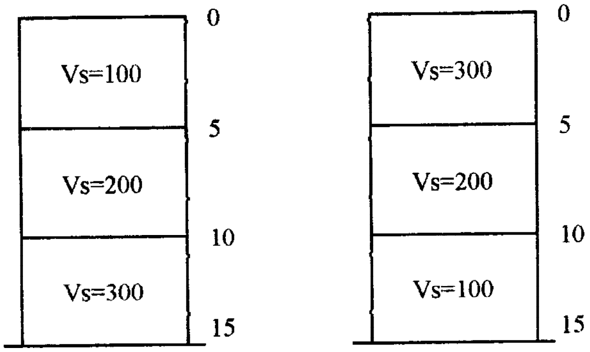

Figure 1. Two generalized soil profiles

In order to explore a way to take into account this effect, a procedure for rating sites is presented in this paper.

STRONG MOTION DATA BACKGROUND

Strong ground motion observation data are essential to establish any kind of procedure for determining design response spectrum. However, number of shear wave velocity profiles where free field motion(s) was(were) recorded with valuable amplitudes for engineering purpose is limited. Data of 85 profiles from the western part of the United States (Duke et al., 1962, USGS, 1980,1981,1982) and 235 response spectra recorded on these sites (CIT,1973) are collected. In total 85 sites, there are 18 rock with 40 recordings, 22 hard with 50 recordings, 21 stiff with 58 recording and 24 soft/medium stiff sites with 87 recordings, and in 67 soil sites, thickness of 52 sites are larger than 20 meters. The recordings cover a range of magnitude from 3.5 to 7.0, epicenter distance from a few kilometers to several hundred kilometers and intensity from five to nine.

Design response spectrum in building code is usually simplified as trisegment shape, an ascent par for period less than T_1 , a horizontal part for period between T_1 and T_2 , and a descent part for period larger than T_2 . In general, T_1 may be assigned a value of 0.1 to 0.2 seconds, T_2 may varies from 0.1 to 0.6 seconds depending on the site category, the descent rate is about 1.0, and the design spectrum just cover the period range less than 3.0 seconds (Martin et al., 1994). As urbanization, high rise buildings, long span bridges are getting popular, therefore the design spectrum is requested to extend at least doubly. Refer to the classic Newmark-Hall method, one could request this long period portion of the spectra to be controlled by nearly constant spectral displacement. Therefore, a four segment design spectrum is adopted in this paper and is shown in figure 2. The fourth part of the spectrum, descends with a rate of $(T_2\ T_3\ /T^2\ )$.Shapes of the actual

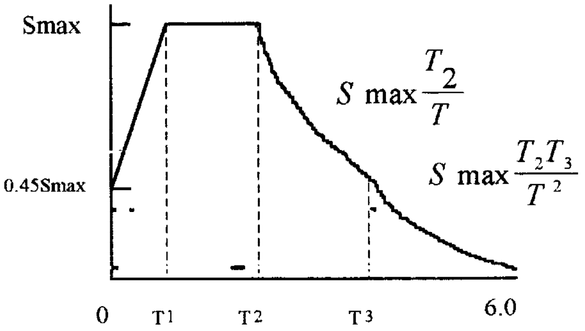

Figure 2. Four segment design response spectrum

recorded response spectra are rather complicated, and usually described by several tens amplitudes. Thus, they must be simplified before any statistical process. Firstly, a spectrum was smoothed by Hanning window, then four spectral parameters were acquired from the smoothed spectrum by four dimensional best trial fitting.

SITE TRANSFER FUNCTION

Site transfer function for one dimensional shear wave propagation was selected to describe the site characteristics, since it is the last modifier of seismic wave to the ground and it varies not only with the average indexes, but also with the soil layer combination. The wave amplitude transfer matrix between ground surface and underlying rock surface could be derived as follows.

$$R(\omega) = \prod_{j=1}^{N-1} T_j(\omega) \tag{1}$$

where $T_j(\omega)$ is the transfer matrix between the bottom and top surfaces of the jth soil layer.

$$T_j(\omega) = \begin{bmatrix} \frac{1+\alpha_j}{2} e^{ik_j h_j} & \frac{1-\alpha_j}{2} e^{-ik_j h_j} \\ \frac{1-\alpha_j}{2} e^{ik_j h_j} & \frac{1+\alpha_j}{2} e^{-ik_j h_j} \end{bmatrix} = \begin{bmatrix} t_{12} & t_{21} \\ t_{21} & t_{22} \end{bmatrix} \tag{2}$$

where $\alpha_j = (\rho_j Vs_j)/(\rho_{j+1} Vs_{j+1})$ is called complex impedance ratio between the j th and the $j+1$th soil layers and Vs is the complex wave velocity, k_j and h_j are the complex wave number and thickness of the j th soil layer, respectively. Since the shear stress at ground surface equals to zero, the site transfer function could be derived as

$$H(\omega) = \frac{2}{t_{11} + t_{12}} \tag{3}$$

The transfer function for each site profile was calculated at 66 periods. The eighty-five transfer functions show that there is a predominant peak at frequency corresponding to the soil natural period. At very long period range, transfer function decreases to 2.0, i.e. ground response is similar, and the function decreases to zero at extreme short period, i.e. ultra high frequency input will be dissipated in soil and hardly propagate to the surface. For engineering purpose, the function segment with amplitude grater than 2.0 is significant. In order to minimize number of parameters for describing transfer function, four parameters, P, P_1, P_2, P_3 were acquired in a similar process with the one for simplified response spectra. P is the peak value, P_1, P_2, P_3 are periods at which the

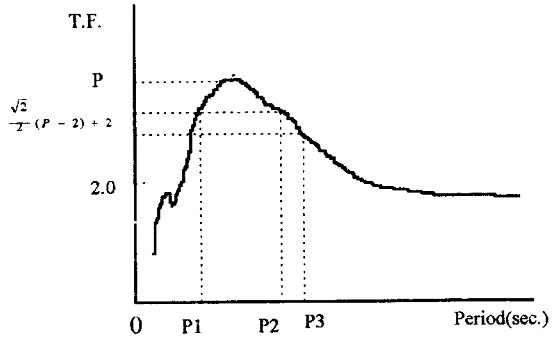

Fig. 3 Characterizing site transfer function

function meets upward $\frac{\sqrt{2}}{2}(P-2)+2$, downward $\frac{\sqrt{2}}{2}(P-2)+2$, and $\frac{1}{2}(P-2)+2$, respectively, as shown in figure 3.

RELATIONSHIP BETWEEN SITE PARAMETERS, EARTHQUAKE ENVIRONMENT AND DESIGN RESPONSE SPECTRA

The four parameters of site transfer function mentioned above were taken as the first set of site parameters. The second set consists of following five parameters: (1) V_s, the average shear wave velocity of site soil, (2) site characteristic period, $T_s = 4H/V_s$, where H is the total thickness of the soil, (3) $V_{\min}/V_s$, ratio of minimum shear wave velocity of soil profile to the average value, (4) $d_{V\min}/H$, ratio of depth of soil layer with minimum velocity to the total thickness of the site soil, (5) $h_{V\min}/H$, ratio of the thickness of the layer with the minimum velocity to the total thickness of the site soil.

An Artificial Neural Network approach is adopted to establish the relationship between site parameters, earthquake environment and design response spectra parameters. Through the auto-organization of the internal links, the neural network is provided with an adaptability to data. The neuron adopted is a nonlinear transformation unit with multiple inputs and single output, the general formula is defined by

$$X_{is}^{k} = \frac{1}{1+e^{-\sum_{j=0}^{N_{k-1}} W_{ij}^{k-1} X_{js}^{k-1}}} \tag{4}$$

where X_{is}^{k} is the output of the i th neuron in the k th layer for the s th sample input; X_{js}^{k-1} is the j th input of the i th neuron in the k th layer, i.e. the output of the j th neuron in the $(k-1)$ th layer for s th sample input; W_{ij}^{k} is the link strength between the i th neuron in the k th layer and the j th neuron in the $(k-1)$ th layer, and is called as a weight; $X_{0s}^{k-1} \equiv 1$, is the additional node of the hidden layer or input layer.

Neural Network, which consists of multiple layers of neurons, could update the weights, W_{ij} successively by an Error Back Propagation approach to reduce the error between its output and the expected output until the error less than an allowable value. A two layer network (6×5×4) was designed for magnitude, distance and four site parameters as inputs, four spectra parameters as output, as shown in figure 4.

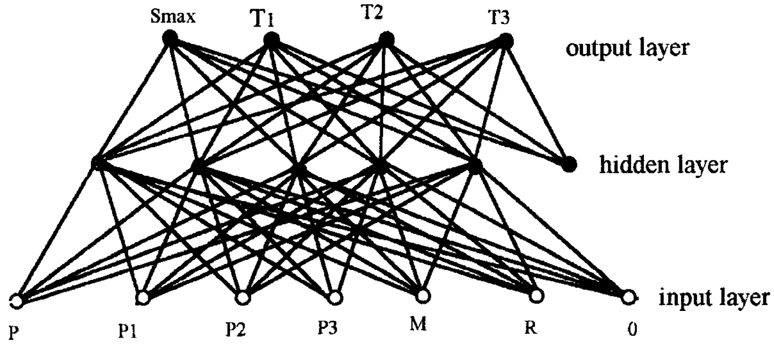

Fig.4. Network for the first set of site parameters

Magnitude and distance were chosen as input to describe the earthquake environment. A network of (7×5×4) was designed for the second set of site parameters. An energy function is defined as follows

$$E_s = \frac{1}{2}\sum_{i=1}^{N_T}(Y_{is} - X_{is}^{T}) \tag{5}$$

where Y_{is} is the expected output of the th neuron of the output layer for the s th sample, X_{is}^{T} is the corresponding output of the network, N_T is total number of the output layer.

By gradient descent method, all weights W_{ij} were modified systematically for increments ΔW_{ij} so that E_s could move a small distance along the negative gradient direction and reduce, i.e. let

$$\Delta W_{ij} = -\alpha \cdot \frac{\partial E}{\partial W_{ij}} \tag{6}$$

where α is a learning rate, in general, taking a value between 0.1 to 1.0.

Substitute eq.(1) and (2) into eq.(3), following equation could be derived

$$\Delta W_{ij}^{k} = \alpha \cdot d_{is}^{k} \cdot X_{js}^{k-1} \tag{7}$$

in which

$$d_{is}^{k} = \begin{cases} (Y_{is}^{k} - X_{is}^{k}) \cdot X_{is}^{k} \cdot (1 - X_{is}^{k}) & \textit{for} \quad \textit{output} \quad \textit{layer} \\ X_{is}^{k} \cdot (1 - X_{is}^{k}) \cdot \sum_{j=0}^{N_{k+1}} d_{is}^{k+1} \cdot W_{js}^{k+1} & \textit{for} \quad \textit{hidden} \quad \textit{layer} \end{cases} \tag{8}$$

is called as propagation error. To accelerate the learning process, an inertia term is commonly added, then

$$\Delta W_{ij}^{k}(n) = \alpha \cdot d_{is}^{k} \cdot X_{js}^{k-1} + \eta \cdot \Delta W_{ij}^{k}(n-1) \tag{9}$$

where n is for the nth learning, η is a coefficient of the inertia term.

At the beginning of the learning, a set of preliminary values were assigned to all weights of the network (e.g. random numbers not equal to zero between -1.0 to 1.0), then input all samples one by one into the network, and update all weights backwards layer by layer after each input. While input of all samples is carried out, it is called as learning once. Learning repeats again and again, the energy function of each sample could reach a required value. The obtained weights are listed in following tables.

Table 1. Weights result for the first set of site parameters

output layer	Smax	-0.105	-1.656	-1.129	0.283	-0.181	-0.061
	T1	0.148	-0.719	-3.582	-0.264	-0.206	0.684
	T2	2.311	11.77	-0.329	-2.868	-2.982	-17.27
	T3	-0.713	-2.572	3.681	0.491	0.302	-0.445
hidden neuron		1	2	3	4	5	0
input layer	P	-25.73	-4.733	1.573	44.56	-69.77	
	P1	4.624	57.17	-34.47	-73.25	40.30	
	P2	110.6	-0.387	3.291	23.87	-18.92	
	P3	-78.96	-7.463	13.61	31.82	66.63	
	M	15.12	8.959	7.457	-40.38	-20.65	
	R	41.23	27.43	-24.88	-21.43	-36.30	
	0	-26.74	-21.14	20.42	-0.926	29.00	

Table 2. Weights result for the second set of site parameters

output layer	Smax	-0.665	-0.160	-0.216	0.191	0.007	-0.061
	T1	-1.161	0.699	-0.848	-1.311	-0.065	0.684
	T2	14.06	3.668	1.997	-1.198	-3.102	-17.27
	T3	-2.081	-1.058	2.136	-0.664	-0.643	-0.445
hidden neuron		1	2	3	4	5	0
input layer	Tx	-9.690	-22.25	6.480	-3.136	-87.12	
	Vs	33.15	53.28	-55.48	-4.260	0.623	
	Vmin/Vs	16.78	48.52	4.592	-21.40	17.91	
	hvmin/H	17.53	-18.43	-8.106	-21.40	-7.706	
	Hvmin/H	-5.657	9.307	24.25	-14.78	-4.477	
	M	-1.298	2.374	-14.87	9.423	-14.12	
	R	7.573	28.07	-5.481	12.54	17.88	
	0	-15.04	-12.34	20.58	30.70	31.85	

VALIDATION OF THE SUGGESTED PROCEDURE

In order to validate the suggested procedure, an average standard deviation was adopted as a comprehensive index, it is defined as

$$\delta = \frac{1}{235}\sum_{i=1}^{235}\sqrt{\frac{1}{66-1}\sum_{j=1}^{n}(S_{ij}-\tilde{S}_{ij})^2} \tag{10}$$

where 235 is the total number of samples, n is the number of each response spectrum amplitudes, S_{ij} is the j th amplitude of the th actual response spectrum, $\tilde{S}_{ij}$ is the corresponding amplitude of design spectrum. The result is shown in following table.

Table 3. Comparison of the average standard deviations

	from the first set	from the second set	from code B	from code S
	0.116	0.106	0.125	0.129

The values calculated from the existing aseismic building codes of China are also listed in the table, for comparison, code B is abbreviation of Design code for antiseismic of buildings, code S is of Design code for antiseismic of special structures. Since the results of the suggested procedure is a internal check in some way, and the design spectra in the building codes only cover a period range from 0 to 3.0 second, all values in above table were calculated on this range on balance. From the table, one could conclude that the procedure presented in this paper improved the existing site rate approach ten to twenty percent.

CONCLUSION

In this paper, a procedure for rating site condition is presented. It emphasizes one of the goals of site rating is to determine the design response spectra, and it takes the combination effect of soil layers into account. The result presented is a network that can derive design spectrum for a given magnitude, distance and site profile. It could be considered as an improvement of site classification.

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