THE GROUND TREMOR AND ITS APPLICATION IN ENGINEERING SEISMOLOGY

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SUMMARY

The ground tremor is a kind of stable random micro-vibration induced by artificial or national disturbances, which can be expressed by the following formula:

M(w)=F(w)*R(w)*S(w)

Where M(w) is the ground tremor, F(w) stands for wave resource, R(w) stands for the transferring medium, and S(w) stands for site. All of the three altogether determine the ground tremor. For a specific site, F(w) and R(w) can be regarded as unchangeable, so spectrum of ground tremor reflects the characters of site such as the type and thickness of its overlying stratum. In the paper, we present the ground tremor spectrum data of loess site in Northwest China got from observations and analysis were also made to discover what these information of the ground tremor in loess site may mean. Actually, the effort is found to be successful

INTRODUCTION

Because of the multi-sources of ground tremor, the intensity of the vibration and the spectrum forms are complex. In a sense, the form of ground tremor resembles that of white noise. If we assume the input of ground tremor as a stable random process, the spectrum can be expressed by M(w), and F(w), R(w). S(w) stand for wave resource, the condition of transferring path of wave and local site conditions. M(w) can be expressed by the following formula:

M(w)=F(w)*R(w)*S(w) (1)

For a specific site of ground tremor, the resource of tremor F(w) and the transferring condition R(w) is identical. So the local site condition is a definitive factor for the characteristic of ground tremor spectrum.

The factors of local site condition include not only the earth's surface topographic, altitude, but also the type of surface stratum, the depth of the ground water, and so on. Being discussed in a comparatively flat areas, the definitive factors for the ground tremor spectrum are the type of overlying stratum structure and its properties and thickness. For different points in a same site, the type of stratum, the constituent, the microstructure and its physics-mechanics characteristic are different. So according to the spectrum, we can judge the type of stratum, the thickness and its characteristic of different sites. In a word, the appliance of the ground tremor is a simple and convenient, economic, accurate method using in dividing the foundation, site evaluation and its choice, slide inspection and prediction, terrestrial heat investigation.

CHARACTERISTIC OF TREMOR AND ITS APPLIANCE IN ENGINEERING SITE EVALUATION

According to a mass of engineering practice of loess area in the Northwest China, the research of the ground

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tremor characteristic is developed step by step.

The relation of ground tremor and strong earthquake motion.

There is great disputed about the relation of ground tremor and strong earthquake motion. Japan scholars represented by Kiyoshi KANAI think that the characteristic of the strong earthquake motion can be predication by the micro-tremor. In American, someone negated intensively that the faint vibration is different with the strong vibration radically. Japan scholars, AO YAMAJI and MASHKAWA CHAJI think that the relation of strong motion and faint vibration spectrum changes according to the foundation conditions.[1]

We had even compared and researched the Fourier's spectrum of Ms 7.2 nearly-field strong earthquake acceleration recorded in Songpan-Pingwu earthquake in 1976 and the Fourier's spectrum of ground tremor recorded in station. The conclusion what we had is that the spectrum characteristic of ground tremor appears in the spectrum shape of strong earthquake motion, but it isn't the major frequency range, which cause the earthquake damage.

When a series of dynamite test had been carried through in the Northwest loess areas of China, we observed the ground tremor before and after the test. Comparing the result of the test and the observation before the test, one of the conclusions is that all the shapes of ground tremor are simulate. But the peak values of horizontal component widen, the spectrum values reduce obviously and the corresponding frequencies move toward the end of low-frequency. Another is that the spectrum shape of the dynamite vibration is very simulate to that of ground tremor before the test. But the peak of frequency band is wider, the value of the spectrum amplitude is higher and also moves toward the end of low-frequency.[2][3]

Both of the above has commonitant on the side of appearance of ground tremor frequency component in the strong earthquake motion. If take no account of difference among large amplitude of earthquake, macrostrain, strong load and micro-range of tremor, strain with small amplitude and low load. When both of them are on their elastic process, the influence of earthquake and ground tremor caused by site stratum is resemble. But the instinct different of vibration resource and its transferring medium between the natural vibration and dynamite is the mainly reason which cause the distinction of both spectrum characteristics. As Kiyoshi KANAI, a Japan scholar, had pointed out:“ the resemblance of ground tremor and earthquake implies a common property which is that both of them are influenced obviously by the foundation vibration.”

The determinative factors of the characteristic of tremor spectrum

Doing seismic microzonation in Xi'an, Several borehole groups had been chosen and studied. The depth of every borehole is over one hundred meter and the distances of poles differ bitter (table 1, figure 1). All above shows that the major factor is the type of site stratum on the measuring point which determine the characteristic of ground tremor spectrum. As the formula provided is: M(w)=F(w)*R(w)*s(w), for the same site, F(w) and R(w) can be assumed constant, and S(w) is a independent variable changing along with site. Similar cases are common occurrence, we can find them in the of ground tremor spectrum maps of Lanzhou, Xining and Tianshui.

The relation of the characteristic of tremor spectrum and the site stratum depth of burial

Because the type of stratum structure is a major factor that decide the characteristic of the ground tremor spectrum, the depth of stratum reflected by tremor spectrum is a important problem of value and its appliance range when they are used for engineering site evaluation. Comparing the dates of some poles and tremor spectrum chosen in Xi'an (the depth of poles is over four- hundred meters), a conclusion can be drawn that the depth of stratum is about 140—190 meters influencing the characteristic of ground tremor spectrum.

The relation of the structural type and the depth of typical surface stratum corresponding to the characteristic of ground tremor spectrum

In the types of stratum, whether and how much the position and depth of different stratums appearing, have effect on the characteristic of tremor spectrum. They decide the sensitivity, veracity and its reliability when the ground tremor used in the side of engineering site evaluation. In Xining seismic microzonation, the new data of fourteen boreholes are compared to the ground tremor spectrum near the boreholes and power spectrum zoning of downtown area.

Xining is a city of river valley. There are different depths of sandy gravel or grits stone under the topsoil. We can draw following conclusions:

1). The super-frequency range of ground tremor spectrum is less than 3.5 Hz as the depth of topsoil is greater than 8 meters and thicker than the depth of sandy gravel which below the topsoil. It just shows the spectrum characteristic of the sort of clays.

2). The super-frequency range of power spectrum is greater than 5.0Hz as the depth of topsoil are less than the depth of sandy gravel or pebble bed which below the topsoil. It just shows the spectrum characteristic of the sort of sandy gravel and pebble bed.
In general, 11 boreholes, 79% of 14 boreholes, show that the characteristic of ground tremor spectrum matches well with the type of topsoil.

3). Analysis of the rest 3 boreholes data shows bad corresponding. Since the depth of clay topsoil is less than that of below sandy gravel, it still reflects the clay's characteristic of tremor spectrum. That is to say, when the difference of Vs (the wave velocity) or $\overline{Vs}$ (the average wave velocity) is greater than 200 m/s, and the depth of clay is greater than 10m, the spectrum is as well as the common ones. It shows that the reflection of the tremor spectrum is accuracy to the changes of site soil's type, characteristics and its depths.

When we have difficult in determining the type of topsoil stratum, better to cooperate with other methods. More studies will be helpful for the determining easily.

Table 1: Comparable table of ground tremor of Xi'an

<table>
<tr><td>borehole's No.</td><td colspan="2">No.1</td><td colspan="2">No.2</td><td colspan="2">No.3</td><td colspan="2">No.4</td></tr>
<tr><td>Position of landforms</td><td colspan="2">Ⅱgrade terrace</td><td colspan="2">Loess yuan</td><td colspan="2">Ⅲ grade terrace</td><td colspan="2">Ⅲ grade terrace</td></tr>
<tr><td rowspan="4">Distance of points(m)</td><td colspan="3">10.5</td><td colspan="2">11.5</td><td colspan="3">0.7</td></tr>
<tr><td colspan="7">10.2</td><td></td></tr>
<tr><td colspan="2"></td><td colspan="6">10.9</td></tr>
<tr><td colspan="8">10.1</td></tr>
<tr><td>The first super-frequency(Hz)</td><td colspan="6"><3.0</td><td colspan="2">5.0</td></tr>
</table>

In Xining seismic microzonation, 24 superficial layer sections were done by physical exploration method in order to remedy the lack of boreholes' data. The coincidence rate is up to 90％—95％ between the conclusion of sections and that of boreholes, which illustrate that the result of physical sections is reliable. In some points, the coincidence rate is up to 83% between the ground tremor spectrum and the type of topsoil (table 2). 4 sections coincide not so well, which lie in the intermediate zone between the clay and the sandy gravel of tremor spectrum zonation.

Consequently, it is reliable using ground tremor spectrum zonation in engineering site evaluation and its types zoning.

The relation of zoning among the ground tremor spectrum, the ground earthquake motion spectrum and the peak acceleration of ground motion

The zoning of ground tremor reflects the spectral response of the Quaternary Period (Q_4), effected by strain with small amplitude vibration. Similarly, the spectrum of ground earthquake motion reflects the spectral response of the surface geologic body during the earthquake, effected by macrostrain and large amplitude vibration. For a special site, the factors, including the spectrum component, intensity and effective duration of the input earthquake waves, have same affection. But for different sites, both the overlying stratums of earth floor and its affection spectral response to the earthquake wave input decide the characteristic of ground response spectrum.

When earthquake motion is on the elastic moment, the forming mechanism is as same as that of ground tremor spectrum. Two of them can be compared together. The tremor spectrum zoning coincide well with the response spectrum of ground motion zoning in Xi'an earthquake microzonation. (Table 3)

Otherwise, the both of them poor match with each other in some partial zonation. There are two major reasons. One is that the errors come from the methods of calculation. When we use 1D or 2D models to calculate the ground motion response. The physical quantity of sublayers of different stratum is calculated by regression equation according to data measured, such as elastic modulus (K), dynamic shear modulus (G), Young's modulus (E), Poisson ratio (μ). Of cause, some errors will be brought out because of the self-errors and the spreading errors. Another reason comes from the self-errors of statistic formulas. When we input earthquake waves into the ground floor, the calculation result of the response cause partly bad correspondence between the ground tremor and ground motion. In general, form the angle of errors, the zoning of ground tremor spectrum reflects the site characteristic more exactly than the zoning of seismic response spectrums.

Table 2: Comparable table of ground tremor zoning and physical sections

Section No.	1	2	3	4	5	6	7	8	9	10	11	12
Tremor zoning	V	III	II	II	V	I	IV	I	V	IV	I	II
Overlying Soil Depth(m)	14.3	12.4	3.25	8.0	10.2	12.6	5.8	11.0	19.9	12.3	4.0	2.9
Depth of gravel stratum(m)	13.8	21.0	4.0	4.0	2.9	5.7	10.1	8.5	19.0	8.0	8.7	7.2
Total(m)	26.1	33.4	7.25	12.0	13.1	18.3	15.9	19.5	38.9	20.3	12.7	10.1
Correspondence	□		□	□	□	□	□	□	□	□	□	□

Section No.	13	14	15	16	17	18	19	20	21	22	23	24
Tremor zoning	II	II	III	I	I	I	III	IV	III	I	I	IV
Overlying Soil Depth(m)	14.8	8.9	6.4	11.7	8.8	16.6	14.7	22.0	21.3	11.9	3.9	3.3
Depth of gravel stratum(m)	11.2	7.7	8.6	6.8	13.7	9.5	9.5	12.0	12.0	5.1	4.1	3.7
Total	26.0	16.6	15.0	17.9	22.5	26.1	24.2	34.0	33.3	17.0	8.0	7.0
Correspondence	□	□		□	□	□		□		□	□	□

Table 3: Comparable zoning based on table of tremor power spectrum and zoning based on ground motion response spectrum near the 14 boreholes

Seismic risk level	Response spectrum zoning		Tg (sec)	α_0 (gal)	Tremor spectrum zoning				
	zone	Secondary zone			I <2.5	II 2.5-<3.5	III 3.5-<5.0	IV 5.0-<8.0	V ≥8.0
Probability of exceedence 10%in 50years	I	I	0.25	125					
	II	II$_{-1}$	0.35						
		II$_{-2}$		180	1	1			
	III	III$_{-1}$	0.50	125	1	1	1		
		III$_{-2}$		180		1	1	1	1
Probability of exceedence 2% in 50years	I	I	0.25	220				2	3
	II	II$_{-1}$	0.35						
		II$_{-2}$		330	1	1			
	III	III$_{-1}$	0.50	220					
		III$_{-2}$		330	1	2	2	1	1

Both the response spectrum zoning and the peak acceleration zoning of ground seismic are a kind of expression that reflects two different sides of seismic in the future. So, both of them are match well with each other, for instance, in the cities of Baoji and Tanshui.

The relation between the zoning of ground tremor spectrum and that of loess wet collapse degree

In wide loess areas, water collapse loess include Malan loess (Q_3), formed during epipleistocene, topsoil with width from several to twenties meters, and the Holocene Epoch (Q_4). The results of zoning based on frequency spectrum of ground tremor spectrum and the zoning based on loess of water collapse degree of large-sized pore concord well with each other. The distribution of collapse loess concentrates in the edge of the second terrace and in terraces above the third terrace. The second water collapse zoning and the first self-weight collapse zoning, the third water collapse zoning and the second self-weight collapse zoning mainly distribute the first, the second and the third tremor spectrum zoning. Almost all of water collapse loess zoning are coincide well with the first peak acceleration zoning of seismic motion and the third zoning of response spectrum. The water collapse of loess will decrease and disappear gradually along with the creasing of the water content and the saturation. So in some zone of the first and partly second river valley where the loess has high saturation and water content, the loess has low collapsibility or no collapsibility.

CONCLUSION

Ground tremor is a stable random vibration in small amplitude of strain induced by natural and artificial distribution. Based on the research of much ground tremor observation, several typical topsoil stratums have the following characteristics. (Figure 2)

1. Though the strong earthquake motion spectrum shows something of the ground tremor spectrum, it shows primarily the characteristics of the earthquake.

2. The form of spectrum of ground tremor depends on the overlying stratum within depth of 140-190m.

3. Four typical profiles of overlying soil were shown as well as their power spectrum and frequency ranges.

4. The power spectrum of ground tremor corresponds well with the response spectrum of ground motion and zonation based on peak acceleration. Since no computation errors exist in zonaton based on the power spectrum of ground tremor, it reflects the elastic vibraton characteristic of overlying soil more accurately.

5. Especially, the zonation based on power spectrum of ground tremor is a better indication of wet collapse of loess.

All above is a section research about ground tremor of loess areas in the Northwest of China, and there are still more works to be done in-depth. In order to enlarge the use of ground tremor in engineering site evaluation, research must be go on in the basis of cognition to the tremor mechanism.

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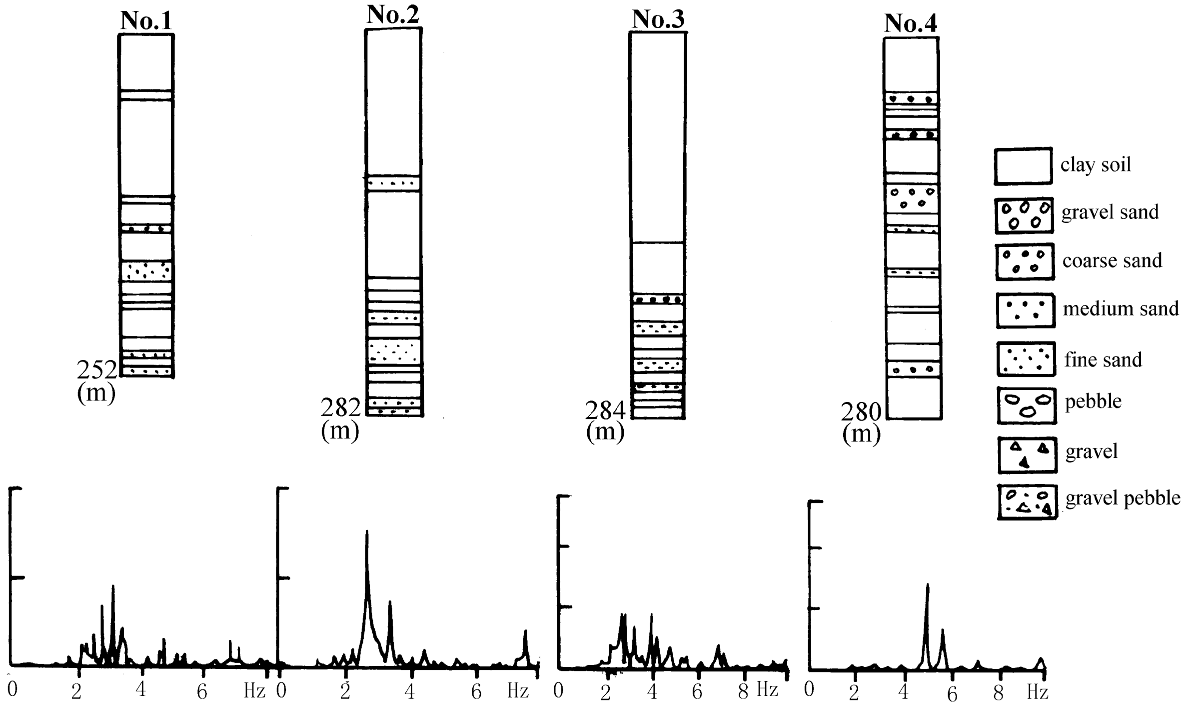

Fig.1 Correlation ground tremor spectrum of Xi'an city

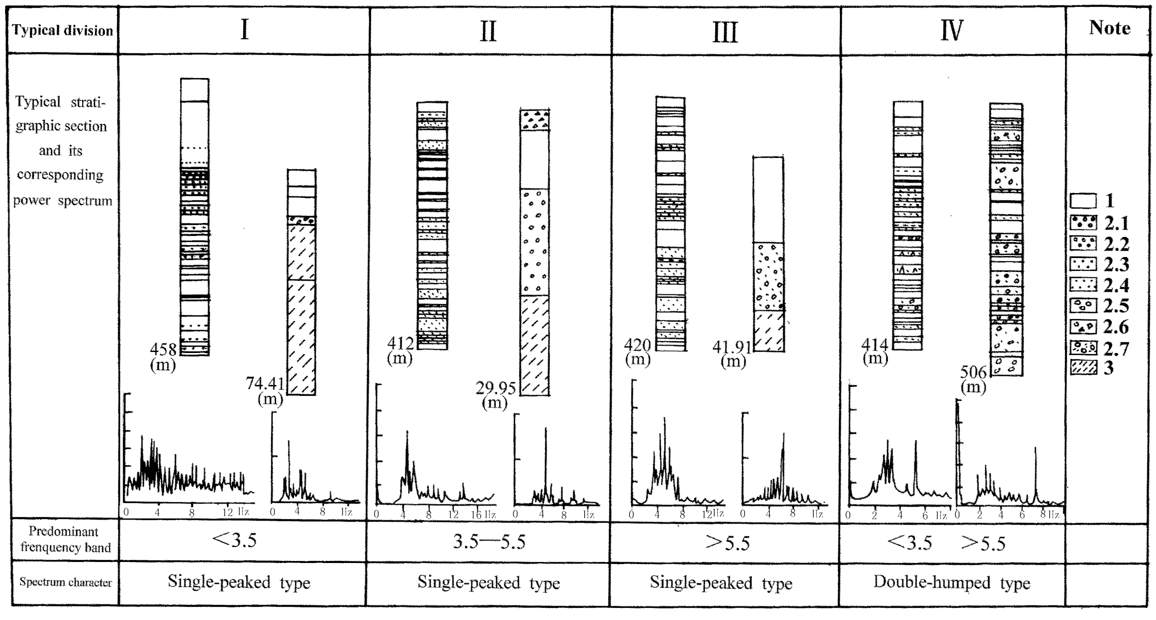

Fig.2 Ground tremor power spectrum property and character of typical stratigraphic section
Note: 1.clay 2.1—2.7. gravel sand, coarse sand, medium sand, fine sand, pebble, gravel, gravel pebble 3.mud rock