APPLICATION OF SHEAR WAVE VELOCITY ON SEISMIC MICRO-ZONING

Shou Peixiu[I], Liu Zengwu[II], Xu Yiaotin[III]

SUMMARY

Based on the experiences of earthquake damage suffered in three large earthquakes of China in the last decade, this paper suggests a criterion, called average shear modulus, for evaluating the effect of site soil condition on ground motion in earthquake. This criterion can be used also in micro-zoning of a city. Examples are given too.

INTRODUCTION

It is well known that earthquake damage to buildings is closely related with soil conditions at the site. Therefore, it is an urgent need to find an engineering criterion for measuring the effect of soil condition upon damage so as to provide an approach for selecting proper construction site in aseismic design. Based on the damage investigation in the Tonghai earthquake (M=7.7) of 1970, the Haicheng earthquake (M=7.3) of 1975 and the Tangshan earthquake (M=7.8) of 1976, as well as results of measurement of elastic wave velocity, it is found that there is a relation between the damage and the elastic wave velocity. In case of multilayer soil, average shear modulus is much correlated with damage. By means of the average shear modulus and other engineering geology data, an approach is suggested in the paper to evaluate the seismic micro-zoning based on soil condition in a city (or district). The approach has been used in Qinhuangdao City as well as in other locations.

RELATION BETWEEN ELASTIC WAVE VELOCITY ON THE GROUND SURFACE AND DAMAGE TO BUILDINGS

Measurement of longitudinal and shear wave velocities was carried out at the sites of the Tonghai earthquake, the Haicheng earthquake and the Tangshan earthquake respectively. In order to emphasize the effect of soil condition on earthquake damage, we strived to eliminate the effect due to other factors, such as topography, tectonic structure and epicentral distance in the selection of testing site.

Damage degree at the site is determined by the damage index(I) of buildings in the location investigated.

The relation between I and longitudinal wave velocity V_p as well as shear velocity V_s are shown in Fig. 1 and Fig. 2 respectively. It is noted that there seems no obvious correlation between wave velocity, either longitudinal wave velocity or shear wave velocity, and damage index.

AVERAGE SHEAR MODULUS G_a OF SOIL LAYERS

By the past experience, it is known that, in addition to the dynamic

---

I, II, III Research Associate, Institute of Engineering Mechanics (IEM), Chinese Academy of Sciences.

properties of structure as well as the characteristics of earthquake input, the stiffness and thickness of soil layers and even the position of layer, play an important role in damage to buildings during earthquake. In order to describe the earthquake effect of site soil, we take the average value G_o of dynamic shear modulus of soil layers which is expressed as follows

$$G_o = \sum_{i=1}^{n} h_i G_i / H$$

where, h_i is the depth of the i-th layer, in meter; $H = \Sigma h_i$, it is reasonable to take H as 20 meters for low-rise buildings; $G_i = \rho_i V_{si}$ indicates the dynamic shear modulus of the i-th layer, in t/m^2, and again in which ρ_i and V_{si} indicate the density in ts^2/m^4 and the shear wave velocity in m/s respectively.

Fig. 3 shows the relations between I and G_o in the Haicheng and the Tonghai earthquake. Fig. 4 shows the relation between I and G_o in the Tangshan earthquake. The said relation can be expressed as

$$I = a - b\, G_o$$

where, a and b are constants determined by the least square method which vary with different earthquakes. It is apparent that some precise relation does exist between them. Results of measurement in the southern part of Tianjin and in the downtown of Qinhuangdao, shown in Tables 1 and 2, also verify such relationships.

APPLICATION OF AVERAGE SHEAR MODULUS IN SEISMIC MICRO-ZONING

The linear relation between damage to buildings and average shear modulus indicates that the greater the value of G at the site location, the less damage will be suffered, and vice versa. Hence it is able to use G_o as an engineering measure in seismic micro-zoning, in addition, distribution of earthquake damage can be predicted.

Four steps are taken in seismic micro-zong when using G_o as an engineering measure:

1. Collect data of engineering geology and hydraulic geology, required in micro-zoning. Divide the investigated area into unit squares (area of which is about 1-0.5 km^2) forming a measurement network. Then proceed with boring, standard penetration, elastic wave velocities measurement of soil layers and tests of physical properties of soil in each unit square. If the geological condition is known, number of measuring points can be reduced. The values of G_{oj} for all measuring points are then calculated based on the boring log, shear wave velocity and density of soil.

2. Based on the concept that seismic intensity is an average measure, the average shear modulus of all measuring points in the whole region is calculated by the formula: $\bar{G}_o = \frac{1}{n} \sum_{j=1}^{n} G_{oj}$ It represents the average tendency of soil condition in that region and should relate with the basic intensity in the same region. Furthermore, assuming that the distribution of G_{oj} is a normal distribution, then, according to the point of view of probability, it is apparent that most values of G_{oj} will locate in the neighbourhood of $\bar{G}_o$. In order to fulfil the requirements of safety and economy, the mean square root (σ) of $\bar{G}_o$ or the probable error (r) of $\bar{G}_o$ or some value (d) (depending on the area of the city), selected as the limit of the region. The region which includes all points of $\bar{G}_o \pm \sigma$

is classified as sub-region II, i.e. the region where the effect of soil on earthquake damage is moderate. The region which includes all points greater than $\bar{G}_o + \sigma$ is classified as sub-region I, i.e., the region where the effect of soil on earthquake damage is slight. The region which includes all points less than $\bar{G}_o - \sigma$ is classified as sub-region III, i.e., the region where the effect of soil on earthquake damage is serious. Thus, the whole region is divided into three sub-regions of different soil effect. of course, if the area of the city considered is very large, we can **adjust** the area of region to increase the number of regions such as $\bar{G}_o \pm d$, $\bar{G}_o \pm 2d$, ... etc; also, we can divide the whole city into several parts according to the natual condition or administration district and then carry on micro-zoning for each part.

The above mentioned classification is only suitable when no damage information of the region is available. But when detailed damage information is available, correlation between G_o and I of the region should be established and used in micro-zoning directly. Considering earthquake is a random process, with reasonable estimation of the variation of earthquake intensity, such relation can be modified appropriately and then used as a criterion for seismic micro-zoning in that area.

3. Finally, the approach can be modified further in combining with other factors such as geological background, the predicted earthquake distribution around the location, effect of topography and faulting, probable existence soil liquefaction and slope sliding.

4. After the classification of sub-region, by means of H. B. Seed's method, earthquake response calculations are made for certain different soil layers in each sub-region considered. It is better to use earthquake record of the region as an input on the base in the calculation, with the chief parameters adjusted. Of course, the peak max. acceleration should be specified in accordance with the basic intensity given on the Map of Seismic Zoning, given by the State Seismological Bureau, China, (sometimes also called the macro-zoning map). The predominate period and duration should be adjusted in referring to the seismic activity or simulation of far earthquake and near earthquake. The average acceleration response spectrum of each sub-region is then used as the standard spectrum for earthquake resistance design of building.

Generally speaking, the procedure we suggest here is rather rough and applicable only to low-rise buildings. For high-rise buildings and for other special structures, it needs some special considerations. We have to emphasize again that the zoning mentioned above is a tentative one and the measured local S wave velocity should be used.

According to the method mentioned above, the maps of seismic micro-zoning of Qinhuangdao City and the damage distribution of the city in the Tangshan earthquake on July 28th, 1976 are made as shown in Fig. 5. It can be seen that both are in good agreement.

REFERENCES

1. Liu Zengwu, Tao Xiaxin and Shou peixiu et al, 1976, "Relation between elastic wave velocity and earthquake damage", Research Report of IEM.

2. Field Investigation Group in the Tonghai earthquake, 1977, "Intensity distribution and the effect of site", Collected Papers on Earthquake Engineering, IEM, Vol. III, pp. 1-14.

3. Seed, H. B. et al, 1978, "Site-dependent spectra for earthquake-resistant design", BSSA, Vol. 66, No. 1, pp. 221-243.

4. Shou Peixiu and Xu Yueting et al, 1978, "Seismic microzonation in the harbour district, Qinhuangdao City", Research Report of IEM.

Table 1. Damage-average shear modulus relationship for the southern part of Tianjin

Location	I*	G_0 (T/m^2)
Guo Huang Zhuang	0.2	9.08×10^3
Nan Ma Ji	0.3	6.01×10^3
South of Bai Dang Gou	0.2-0.4	5.92×10^3
North of Bai Dang Gou	0.4-0.6	5.42×10^3
Xi Shan He	0.4-0.6	5.46×10^3
Qian Shan He	0.4-0.6	4.79×10^3

Table 2. Damage-average shear modulus relationship for Qinhuangdao

	Location	G_0 (T/m^2)
Seriously damaged region	No 1- No 7	7.0×10^3-8.8×10^3
Moderately damaged region	No 8- No 11	10.3×10^3-11.7×10^3
Slightly damaged region	No 12-No 14	18.0×10^3-26.0×10^3

* Reduced from relation between damage index and intensity obtained in China.

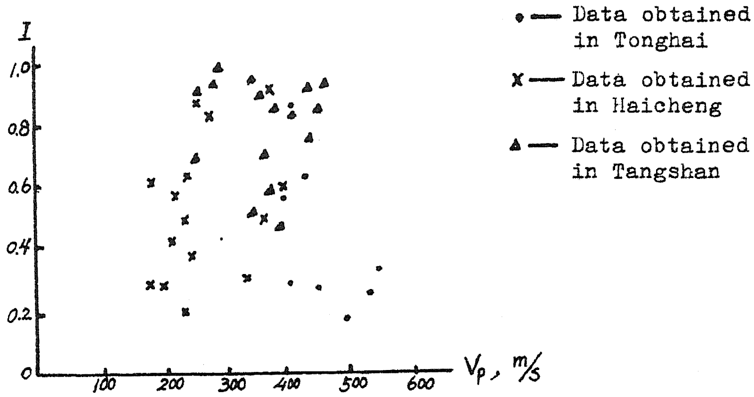

Fig. 1 Relation between V_p and I

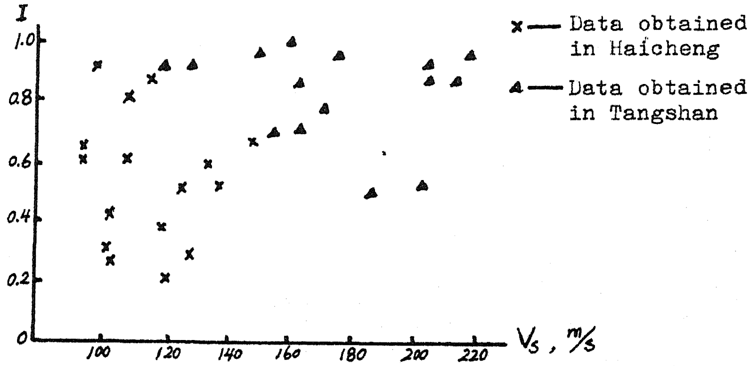

Fig. 2 Relation between V_s and I

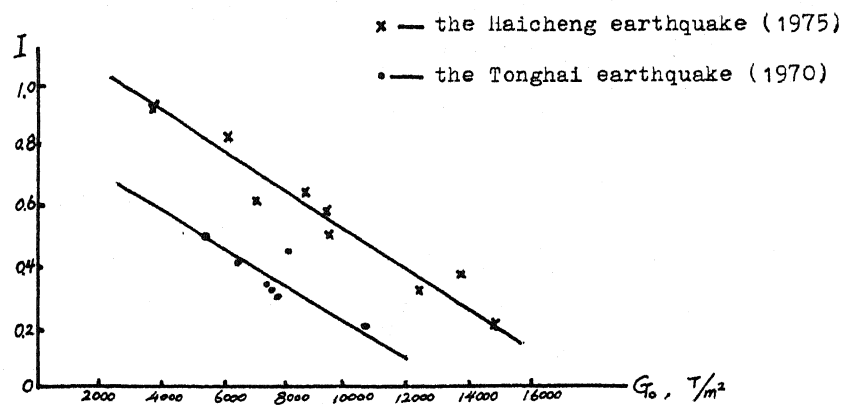

Fig. 3 Relation between damages and average shear modulus for the Tonghai and the Haicheng earthquakes

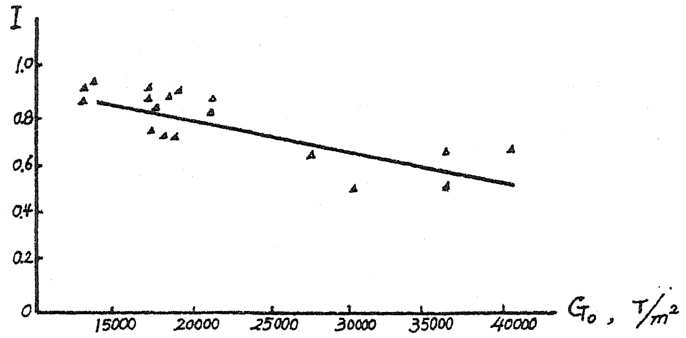

Fig. 4 Relation between damages and average shear modulus for the Tangshan earthquake

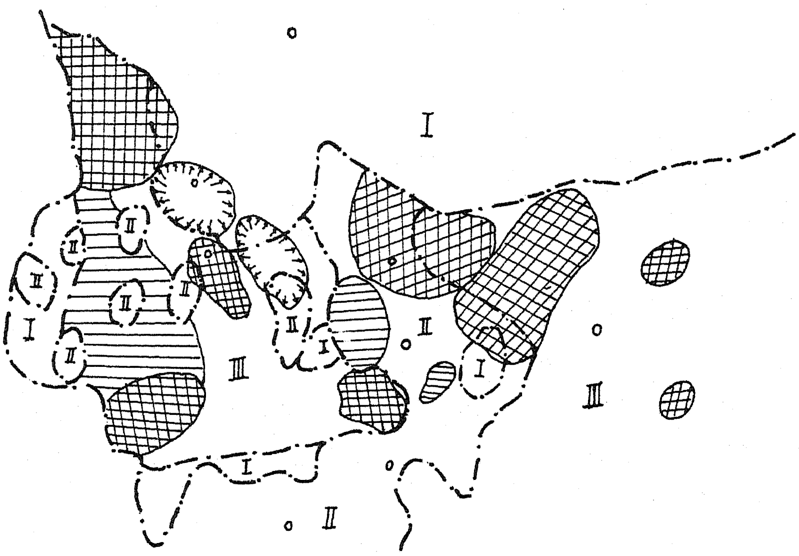

Fig. 5 Microzonation map of Qinhuangdao

o – testing sites; I,II,III – sub-region classified by G_o

seriously damaged — moderately damaged

slightly damaged