STUDY ON THE PHYSICAL MEASURE OF SEISMIC INTENSITY

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ABSTRACT:

The isoseismal of seismic intensity of Chi-Chi Earthquake is plotted based on the seismic damage to buildings subjected to this devastating earthquake. Then the study calculated the average value of Einput (input energy), Eh (hysteretic energy), PGA (peak ground acceleration), PSV (peak spectrum velocity), Arias intensity, EPA (effective peak acceleration), PGV (peak ground motion velocity) and PSD (peak spectrum displacement) of station records in each intensity zone. The linear regression between the average value and the seismic intensities based on the least-square method are carried on. The result shows that Einput, Eh, PGA, PSV, Arias intensity and EPA have good correlation with the intensity and they can serve as the physical measure of seismic intensity. The conclusion drown by this paper is based on the records and damage data of the single Chi-Chi earthquake. Hence, the conclusion is more scientific and authentic in comparison with the results from data of different earthquakes before.

KEYWORDS: isoseismal of seismic intensity, ground motion parameters, linear regression, physical measure of seismic intensity

1. INTRODUCTION

The study on the physical measure of seismic intensity has a history of over 100 years, which can be traced to the beginning of last century. The main aim of the study is to find appropriate ground motion parameter that can reflect both the earthquake damage intensity and the damage degree. Also, the parameter should correlate well with the seismic intensity and can be quantified to apply to the astigmatic design ultimately. Subject to the absence of historic earthquake data the scholar in the past had to carry out the study based on the accumulated earthquake records and damage material. While, the record and material is gathered from the five continents and spans several centuries which is still insufficient to the study of physical measure of seismic intensity. What's mare, different earthquakes have different source mechanism, ground motion characteristics, damaged structures and seismic intensity evaluation method [1]. Hence, the method to study physical measure of seismic intensity based on the mixed data and material retards the advance the field. In recent years a series of devastating earthquakes have occurred in China and abroad especially the Chi-Chi earthquake in Taiwan in 1999. After the Chi-Chi earthquake much structure damage material and ground motion data has been gained in the same single earthquake for the first time, which supplies the first-hand data for the study of earthquake engineering [2]. The key character of this study on physical measure of seismic intensity is that it is conducted based on the abundant records and specified damage material from Chi-Chi earthquake—the single earthquake for the first time.

2. SUMMARY OF EARTHQUAKE GROUND MOTION PARAMETERS

As mentioned above, the physical measure of seismic intensity should correlate well with the structure response. Earthquake ground motion parameters can be compartmentalized to three kinds according to their characteristic: amplitude parameter, frequency parameter and duration parameter and these three characteristics are the three basics of earthquake ground motions. With the development of research of ground motion energy parameters more and more attention has been paid to the structure damage affect of energy parameters in recent years. Fifteen parameters are chosen according to the characteristic of ground motion in this paper. Theses parameters are very common in the study of earthquake engineering and can reflect the various characteristic of ground motion to some degree. The correlation coefficient between these parameters and response of masonry and concrete structures is calculated in this study and 6 parameters are confirmed which can reflect the damage potential of earthquake ground motion to most structures. These six parameters are followed:

PGA（peak ground motion acceleration）

PGV（peak ground motion velocity）

PSV（peak spectrum velocity）、PSD（peak spectrum displacement）

EPA is the average of the spectral ordinates of the elastic acceleration response spectrum S_a (for 5% critical damping) in the period interval [0.1s, 0.5s], divided by a standard value 2.5. It is defined by the following relation

$$EPA = \frac{S_{a(0.1s-0.5s)}(\xi = 0.05)}{2.5} \tag{2.1}$$

Arias intensity:

$$Arias = \frac{\pi}{2g}\int_0^t a^2(t)dt \tag{2.2}$$

t is the total seismic duration and $a(t)$ is the ground acceleration

Absolute input energy:

$$E_{input} = \int m v_t d\ddot{v}_t \quad , \quad v_t = v + v_g \tag{2.3}$$

v_g is the ground displacement. v is the relative displacement to the ground of the system and v_t is the absolute displacement.
Hysteretic energy:

$$E_h = \int f_s dv - \frac{(f_k)^2}{2k} \tag{2.4}$$

f_k is the elastic resilience at the moment and k is the stiffness coefficient.

3. THE ISOSEISMAL OF SEISMIC INTENSITY OF CHI-CHI EARTHQUAKE

Soon after an earthquake occurs the damage investigation teams organized by some department enter the disaster area to investigate earthquake damage at the locale. The investigation includes evaluation of damaged buildings, gathering news from the local people and so on. After that, the isoseismal of seismic intensity can be plotted based on the investigation results. Because the Chi-Chi earthquake occurred five years ago, it's impractical to apply the traditional way above to plot the isoseismal. We have no choice but to classify the damage material and plot the isoseismal. As for seismic intensity one to five intensity degree is mainly felt by humans and six to ten intensity degree is mainly reflected by structure damage. In engineering study we are only interested in six to ten intensity degree and pay less attention to low intensity degrees. What's more, in the Chi-Chi earthquake much structure damage material and data is gained which can reflect the effect of intensity degree six to ten. Hence, the isoseismal in this study is mainly plotted based on the structure damage data.
<Macroseismic Scale of China> sets the damage index as the numeral standard to measure the damage degree of structures [3]. The index 1.0 implies structure total collapse and 0 implies structure perfectibility. Interval between 0 and 1 can be divided into several damage classes randomly. The average damage index represents the average value of damage index of all the structures in a specified zone, which equals the sum of product of percentage of various damage degree structures and their corresponding damage indices. The specified numeral standard can be found in Table 3.1. and their corresponding damage indices. The specified numeral standard can be found in Table 3.1.

Table 3.1 The content of damage index corresponding to different seismic intensity

intensity	Ⅵ	Ⅶ	Ⅷ	Ⅸ	Ⅹ	Ⅺ
average damage index	0-0.1	0.11-0.30	0.31-0.50	0.51-0.70	0.71-0.90	0.91-1.00

Average damage index of every zone localized to town and village is calculated and then the pots with same intensity degree are jointed by slick close curve according to the rule of <Macroseismic Scale of China in 1999>. After that, the isoseismal can be gained and it is shown in Figure 1. After Chi-Chi earthquake 214 fine ground motion records were obtained which can apply to the science research [4]. These records are the research base of this study and their distribution is shown in Figure 2.

4. CONFIRMATION OF PHYSICAL MEASURE OF SEISMIC INTENSITY

The average value of Einput, Eh, PGA, PSV, Arias intensity, EPA, PGV and PSD of 214 station records in each intensity zone is calculated. Then the linear regression between the average value and

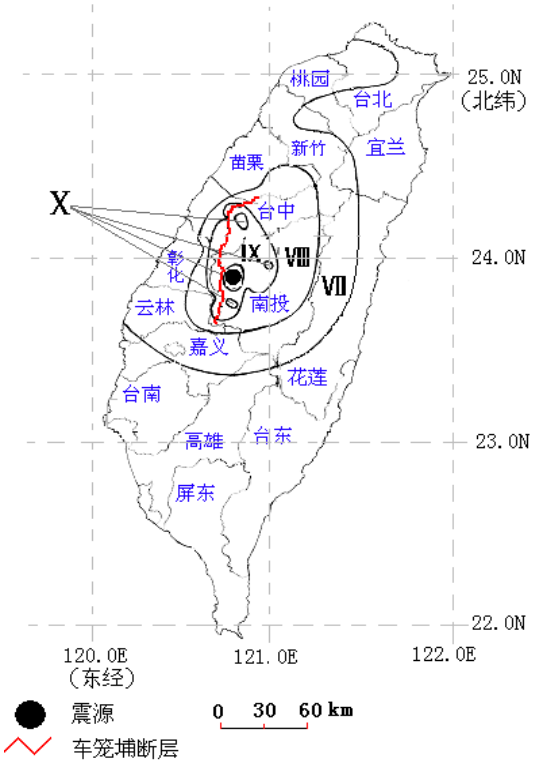


Figure 1 The seismic intensity isoseismal of Chi-Chi Earthquake

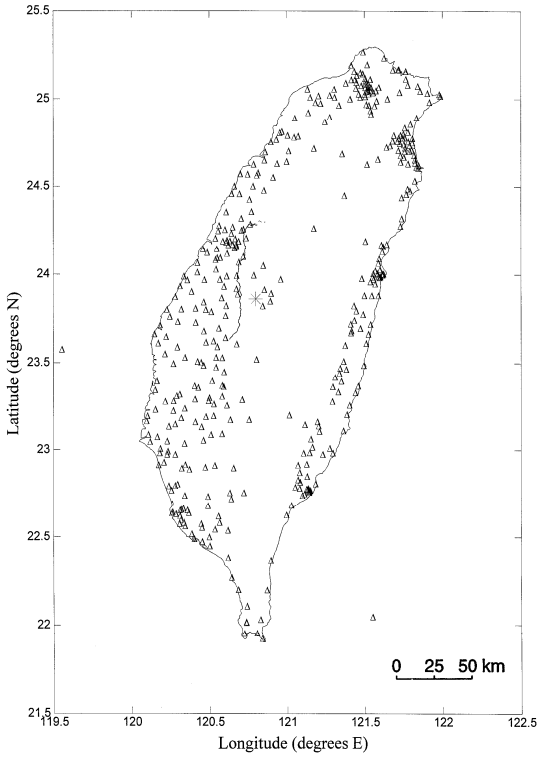
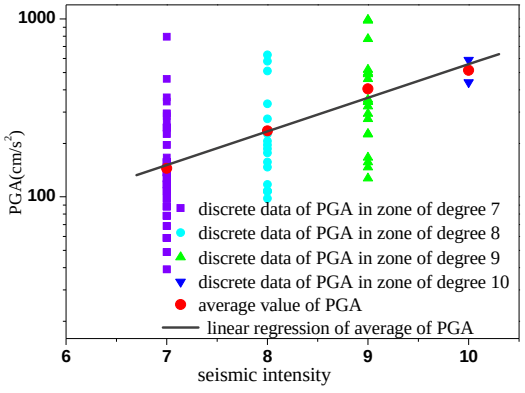
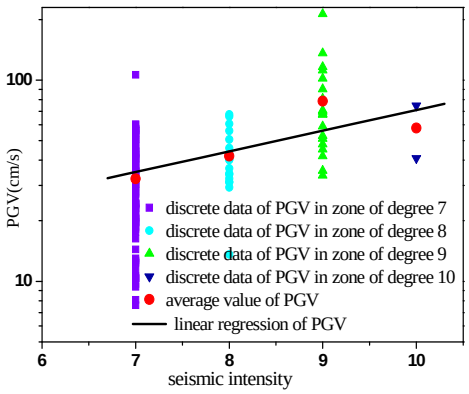


Figure 2 Location of strong-motion records of the 1999 Chi-Chi earthquake

the seismic intensities based on the least-square method are carried out respectively. The results are shown in Figure 3.





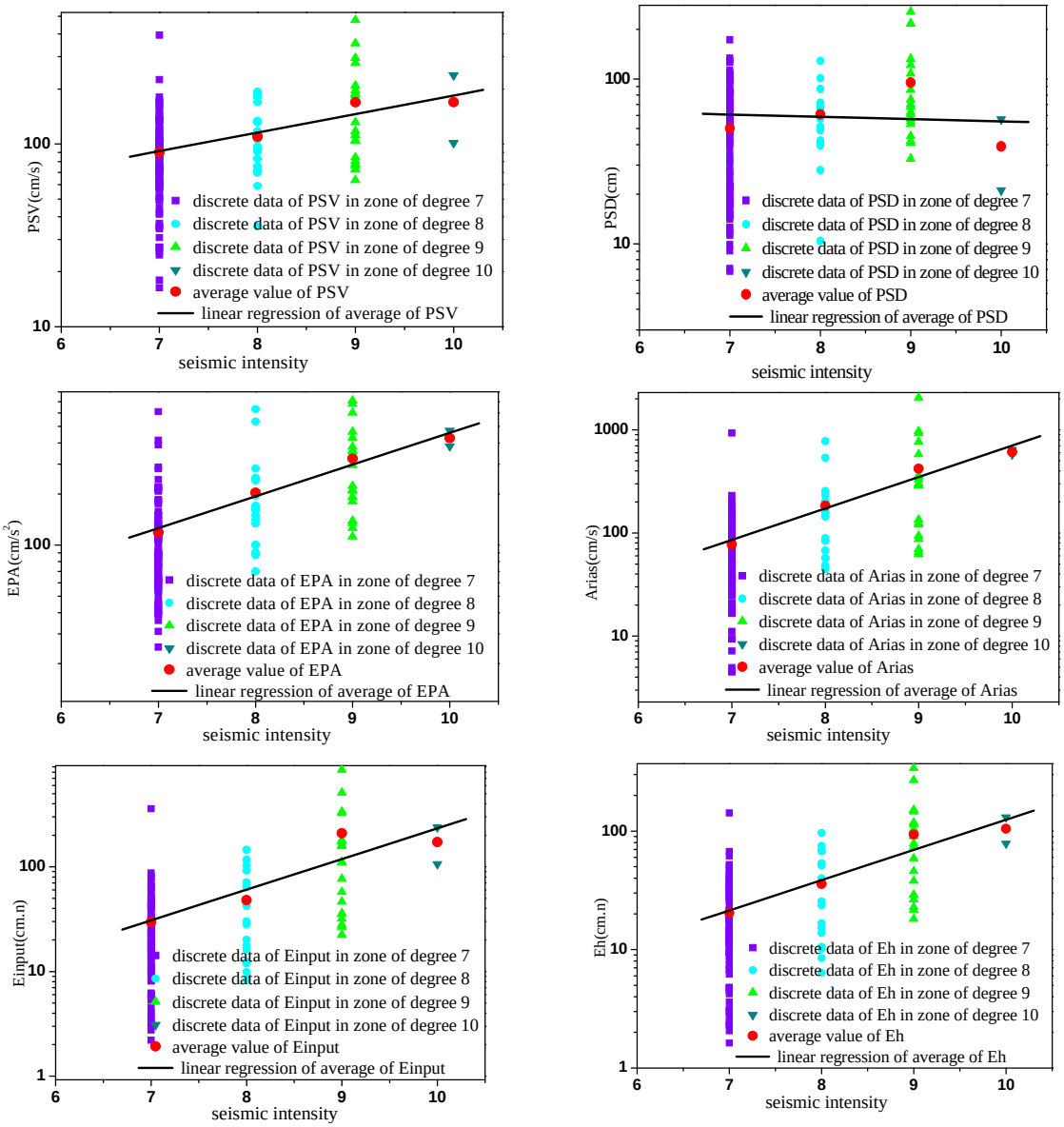


Figure 3 The scatter of the 8 ground motion parameters in different seismic intensity zones and the linear regression between the mean value of the parameters and the seismic intensity

The linear regression equations between these parameters and intensities are set. Because the correlation coefficient can display the relativity between two random variables best this study adopt the correlation coefficient to scale the relativity between ground motion parameters and intensities. The linear regression equations and corresponding correlation coefficient are followed.

$$I = -4.53 + 5.29\lg\overline{PGA} \qquad R = 0.989 \tag{4.1}$$

$$I = -8.08 + 9.8\lg\overline{PGV} \qquad R = 0.792 \tag{4.2}$$

$$I = -12.4 + 9.9\lg\overline{PSV} \qquad R = 0.947 \tag{4.3}$$

$$I = 134.36 - 71.43\lg\overline{PSD} \qquad R = -0.109 \tag{4.4}$$

$$I = -4.23 + 5.35\lg\overline{EPA} \qquad R = 0.991 \tag{4.5}$$

$$I = 0.66 + 3.28\lg\overline{Arias} \qquad R = 0.986 \tag{4.6}$$

$$I = 1.92 + 3.41\lg\overline{Einput} \qquad R = 0.911 \qquad (4.7)$$

$$I = 1.79 + 3.92\lg\overline{Eh} \qquad R = 0.965 \qquad (4.8)$$

The linear regression equations and corresponding correlation coefficient above show that the correlation coefficient between PGA, PSV, EPA, Arias intensity, Einput, Eh and intensity is above 0.9 which indicates these 6 parameters correlate well with the intensity and they can consider to serve as the physical measure of seismic intensity.

5. CONCLUSION

The isoseismal of seismic intensity of Chi-Chi Earthquake is plotted based on the seismic damage to buildings subjected to this devastating earthquake. Then the study calculated the average value of Einput, Eh, PGA, PSV, Arias intensity, EPA, PGV and PSD of station records in each intensity zone. The linear regression between the average value and the seismic intensities based on the least-square method are carried out. The results are followed:

1 Einput, Eh, PGA, PSV, Arias intensity and EPA have good correlation with the intensity. Especially the regression coefficient between EPA, PGA, Arias intensity and intensity is near to1.these 6 parameters can serve as the physical measure of seismic intensity.

2 The conclusion drown by this paper is based on the records and damage data of the single Chi-Chi earthquake. Hence, the conclusion is more scientific and authentic in comparison with the results from data of different earthquakes before. The physical measure of seismic intensity put forward by this study can provide the base for the aseismatic design of China. Also, the results from this study can provide reference for the future macroseismic scale and criterion of seismic resist design.

REFERENCES

HAO Min, XIE Li-li. (2005). Some considerations on the physical measure of seismic intensity. *ACTA SEISMOLOGICA SINICA* **18:2**, 245-250

Institute of Structure of Department of Interior in Taiwan. (1999). Preliminary report about the investigation of structure damage of 921 Chi-Chi earthquake, Taiwan.

GB/T 17742-1999，《Macroseismic Scale of China in 1999》

K.C.Tsai, Chiang Pi Hsiao, Michel Bruneau. (2000). Overview of Building Damages in 921 Chi-Chi earthquake. *Earthquake Engineering and Engineering Seismology* **2:1**, 93-108