STUDY ON THE PHYSICAL MEASURE OF SEISMIC INTENSITY BASED ON THE ENERGY PARAMETERS OF EARTHQUAKE GROUND MOTION

HAO Min [1] XIE Lili [2] **and** LI Wei [3]

[1] *Doctor, Dept. of Civil Engineering, Tsinghua University, Beijing. China*
[2] *Professor, Institute of Engineering Mechanics, China Earthquake Administration, Harbin. China*
[3] *Master, Institute of Engineering Mechanics, China Earthquake Administration, Harbin. China*
Email: haomin2005@126.com, llxie@public.hr.hl.cn, liw959@126.com

ABSTRACT:

The isoseismal of seismic intensity is plotted based on the seismic damage to buildings for the 9.21 Taiwan Chi-Chi Earthquake. Then the paper calculated the average value of input energy and hysteretic energy of ground motions 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 the two energy parameters correlate very well with the intensity. Since the energy parameters can reflect the damage potential to structures 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. So the conclusion is more scientific and authentic in comparison with the results from data of different earthquakes before.

KEYWORDS: isoseismal of seismic intensity, physical measure of seismic intensity, input energy of ground motion, hysteretic energy, correlate

1. INTRODUCTION

Seismic intensity is a macroscopical definition that explains the general measure of overall structure damage in a specified zone after earthquake. The research of physical measure of seismic intensity is a history and basic subject. The physical measure of seismic intensity should correlate well with most structure response and can reflect the damage potential to most structures. Also, the physical measure should correlate well with the intensity. The study of damage potential of earthquake ground motion has been worked on for more than one hundred years. Because of the lack of the material about the seismic damage the study of this field is carried out based on the accumulated earthquake records and damage material. Since different earthquakes have different source mechanism, ground motion characteristics, damaged structures and seismic intensity evaluation the method of mixing different earthquake material with different time and location to study physical measure of seismic intensity is not valid. But this method is unavoidable. Also, though the study before classified the kind of structures it is very cursory and simple. In addition, the ground motion parameters considered only included peak amplitude and few spectrum parameters and the energy parameters were never taken into account. As for this condition the study of physical measure of seismic intensity based on energy parameters using abundant records and specified damage material from Chi-Chi earthquake is conducted in this paper.

2. INPUT ENERGY AND HYSTERETIC ENERGY OF GROUND MOTION

In the physical sense the deformation course of structures subjected to earthquake ground motion can be considered to the course of energy absorb and transformation [1]. During the elastic stage with the increase of structure deformation the energy inputted to the structure by ground motion mount up ceaselessly. Some of the energy is dissipated by structure damping and the other part of energy transforms to the kinetic and elastic energy [2]. Entering the inelastic stage much of the input energy is absorbed by the structure inelastic deformation and this kind of energy is called hysteretic energy. The more the inelastic deformation increase the more the hysteretic energy accumulates. At the same time, the intension and stiffness of structures decreases and declines ceaselessly and finally come to the crash [3]. From this aspect the input and hysteretic energy parameters can reflect the damage potential of ground motion and the definition of the two parameters are followed.
Absolute input energy:

$$E_{input} = \int m v_t d\ddot{v}_t \quad , \quad v_t = v + v_g \tag{2.1}$$

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:

$$E_h = \int f_s dv - \frac{(f_k)^2}{2k} \tag{2.2}$$

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

On September 21st in 1999 a devastating magnitude ML=7.3 earthquake occurred in Taiwan of China [4]. Because Taiwan weather bureau set more than 400 numeral strong motion stations over 400 dense strong motion records were gained after the earthquake. To be more gratified Taiwan province organized many people and material resources to investigate the disaster area and got passel of rare

damage data soon after the earthquake [5], which provide an unprecedented chance and condition to the study of physical measure of seismic intensity. <Macroseismic Scale of China> sets the damage index as the numeral standard to measure the damage degree of structures [6]. 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.

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

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 restricted to intensity degree 6 to 10 and is mainly plotted based on the structure damage data. In this study the isoseismal of Chi-Chi earthquake is plotted by the average damage index. The average damage index of every zone localized to town and village is calculated and the corresponding intensity can be confirmed according to table 1.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.

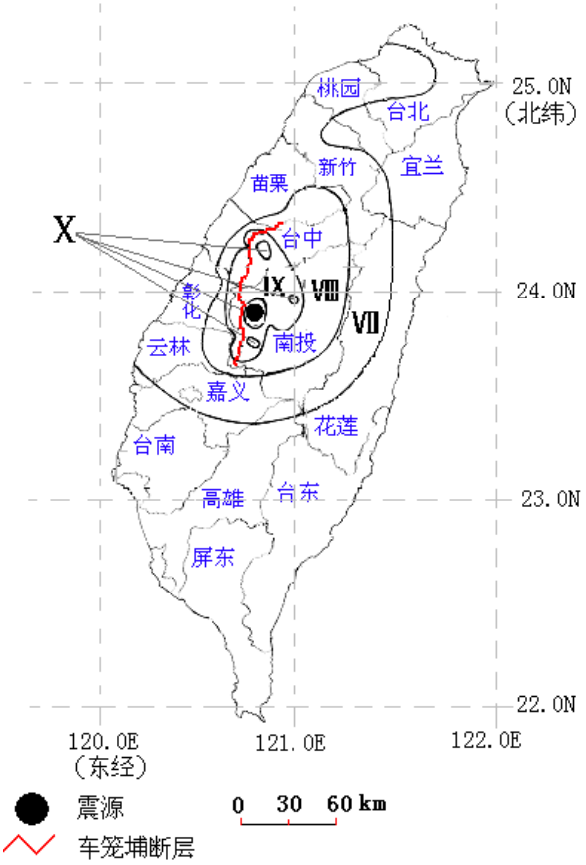


Figure 1The seismic intensity isoseismal of Chi-Chi Earthquake

After Chi-Chi earthquake 214 fine ground motion records were obtained which can apply to the science research. These records are the research base of this study and their distribution is shown in Figure 2.

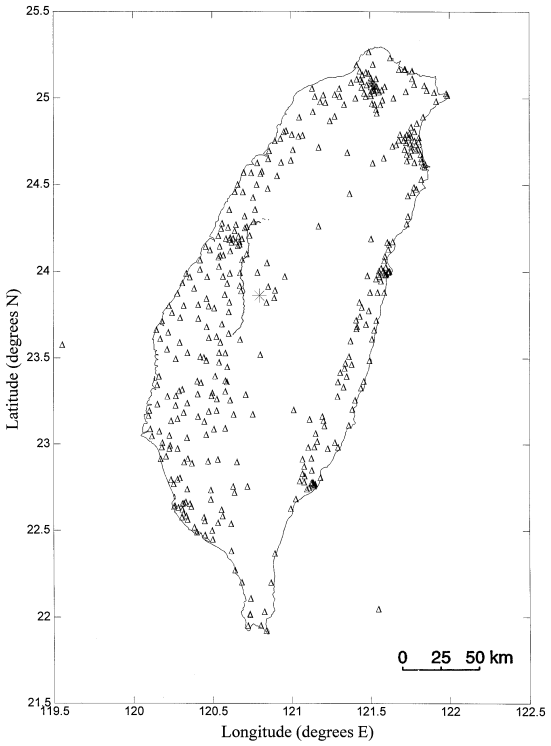
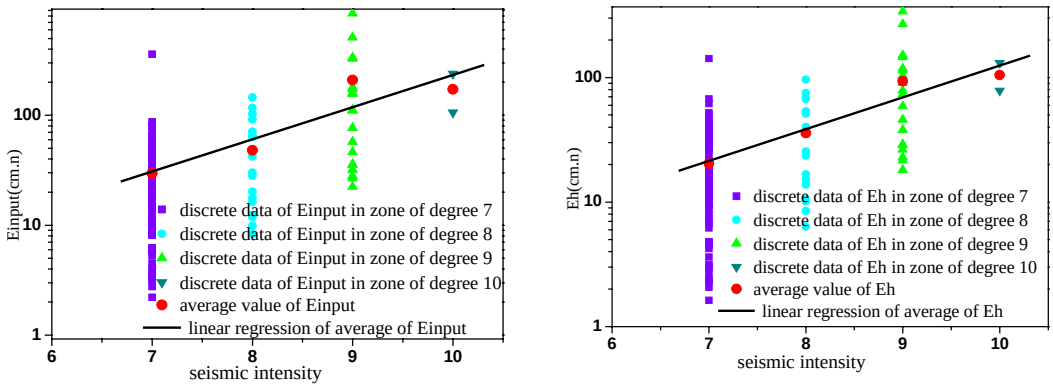


Figure 2 Location of strong-motion records of the 1999 Chi-Chi earthquake

4. STUDY ON THE RELATIVITY BETWEEN ENERGY PARAMETERS OF GROUND MOTION AND SEISMIC INTENSITY

The average value of Einput and Eh of 214 station records in each intensity zone is calculated according to equation 1 and 2. Then the linear regression between the average value and the seismic intensities based on the least-square method are carried out respectively. The results are shown in Figure 3.



(a) (b)

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

In order to judge the regression effect better 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.

$$I = 1.92 + 3.41 \lg \overline{Einput} \qquad R = 0.911 \qquad (4.1)$$

$$I = 1.79 + 3.92 \lg \overline{Eh} \qquad R = 0.965 \qquad (4.2)$$

The linear regression equations 3 and 4 show that the correlation coefficient between Einput, Eh and intensity is above 0.9 which indicates these 2 parameters correlate well with the intensity. As mentioned above, Einput, Eh have consanguineous relationship with the structure response and damnification in theory. According to the principle of confirming physical measure Einput, Eh 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 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 and Eh have good correlation with the intensity. Because the two parameters can reflect the damage potential to structures they 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

XIAO Ming kui, BAI Shao liang. (2003). Maximum Displacement Estimation of Seismic Structures Based on Hysteretic Energy. *Journal of Chongqing University* **26:3**, 133-137

XIAO Ming kui, LIU Bo, BAI Shao liang. (1996). Analysis of the Total Energy and Its Influencing Factors for Seismic Structures. *Journal of Chongqing Jianzhu University* **18:2**, 20-33

NORIO Hori, Norio Inoue. (2002). Damage Properties of Ground Motions and Prediction of Maximum Response of Structures Based on Momentary Energy Response. *Earthquake Engineering and Structural Dynamics* **31,** 1657-1679

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

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

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