Introduce of Three Models for Attenuation of Ground Motions

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SUMMARY:
The circle model and elliptical model are very popular attenuation models of ground motions applied in China. It is obvious that the circle model is not suitable for large earthquakes. Considering the general elliptical attenuation model cannot simulate some characteristics of motion distribution along the large earthquake fault, the four-area elliptical attenuation model and the six-area elliptical attenuation model were suggested. Because the circle model is still useful in seismic risk analysis and the fault distances adopted in some models are not measured easily, we propose one circle model in which the 'epicentral distance' is a mapping of the epicentral distance in the elliptical model. All of the three models and circle model are used to analyze the acceleration attenuation relationship in Wenchuan Earthquake (Ms8.0). The results show that the three models can be used to simulate the motion distribution along the fault and the attenuation relationship in Wenchuan earthquake.

Keywords: acceleration attenuation model, mapping of epicentral distance, Wenchuan earthquake

1. INTRODUCTION

At present, there exist two ways to study peak ground acceleration (PGA) attenuation relationship. The first one is based on researching mechanism of earthquake and transmission process of seismic waves, but it's hard to get accurate attenuation relationship because of the complexity of earthquake itself. On the basis of Haskll's ω-cube radiated spectrum of source model, Liu *et. al* (1989) deduced a PGA attenuation relationship considering effect of directivity of fault. However, there are some defects in the model: (1) the PGA in the epicentral area is not consistent with each other along the different direction; (2) the attenuate rates of every direction are equivalent.

The second way is to study the shape of isoseismal curves. As a typical model, circle model in which isoseismal curves are considered as a series of concentric circles and epicentral distance or hypocentral distance is the only parameter to represent the location of site is widely used throughout the world because of its simplicity and accuracy of predicting PGA of mid-small earthquakes. But for large earthquakes, especially for some earthquakes with long fault, circle model is totally useless. It's obvious that the isoseismal curves of Wenchuan earthquake (Ms8.0) are far from concentric circles (see Fig. 1.1). The other model is fault-rupture model with consideration of the effect of fault on PGA by using the shortest distance of site from ruptured zone as the distance parameter of site. In recent years, the project NGA was undertaken to develop new attenuation models for shallow crustal earthquakes in the western United States and similar active tectonic regions. The five NGA models already published are most commonly based on fault-rupture model and are accurate for earthquakes in the western United States. However, the models are difficult to be widely applied in most other countries because of their complexity. And Shen and Hua (1989) considered that there was more systematic deviation in fault-rupture model for the earthquakes in Eastern China.

So it's necessary to develop a new model that is suitable for most of earthquakes, especially large ones. Three PGA attenuation models are introduced in this paper using records of Wenchuan earthquake.

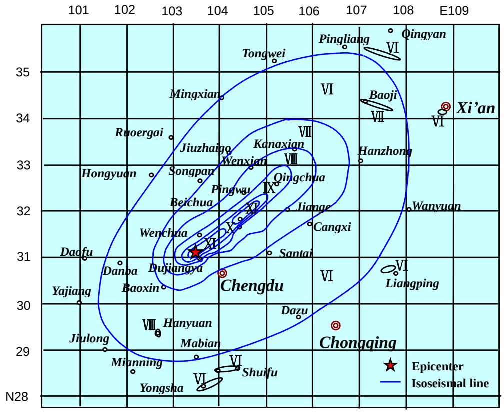


Figure 1.1. The isoseismal map of Wenchuan earthquake (Yuan and Sun, 2008)

2. THREE ATTENATION MODELS

At 14:28:04 on May 12, 2008 (Beijing Time), the Wenchuan earthquake with Ms8.0 occurred in Sichuan, China. The focal depth was 14 km. Meizoseismal area was a long and narrow belt area along the seismic fault, and the seismic intensity in epicentral area was up to Ⅺ. The earthquake affected six provinces, Municipal and Autonomous Regions including Sichuan, Gansu, Shaanxi, Chongqing, Yunnan, and Ningxia. People in over half of China and as far as in Vietnam felt the shaking of this earthquake. The earthquake resulted in not only large numbers of building collapsed but also widespread occurrence of heavy landslide, rolling stones, mudslide, liquefaction, and other geological hazard. A number of people lost their lives in the earthquake and it caused great economic losses.

Based on the detailed field investigation information, the isoseismal map was published in October, 2008 (Yuan and Sun, 2008). China Strong Motion Networks operated in March, 2008 recorded a large number of digital strong motion records with high-quality. The uncorrected acceleration record of Wenchuan Ms8.0 earthquake is also published, which included 1253 records from 420 stations of 19 provinces (Lu and Li, 2008).

Based on the database mentioned above, we propose three attenuation models under the assumption that there is a blurred proportional relationship between PGA and seismic intensity for the same earthquake.

2.1. Four-area Elliptical Model

As shown in Fig. 1.1, there are some characteristics in the isoseismal curves of Wenchuan earthquake as following: (1) the innermost isoseismal curve coincides with the fault; (2) any other ones are close to ellipse. Considering the effect of directivity of fault-rupture and hanging wall on PGA, Yang and Luo (2010a) proposed the four-area elliptical model in which isoseismal map is divided into four areas. The strike direction of fault is the major axis and the direction which is perpendicular to fault and passes through the center of fault is the minor axis (see Fig. 2.1). It is assumed that intercepts of some PGA isoseismal curves at four axes are equal to intercepts of intensity isoseismal curves at four axes. Geometric shapes comprised of quarter- ellipses whose semi-major axis and semi-minor axis are those intercepts is considered as base PGA isoseismal. For a recording, PGA isoseismal passing through the site could be speculated using interpolation principle. The four-area elliptical PGA attenuation relationship is a relationship using intercepts of PGA isoseismal at four axes as distance parameters along four directions. The specific steps of four-area elliptical model of Wenchuan earthquake is expressed as below:

(1) Identify location of the site in the base PGA isoseismal for a recording.

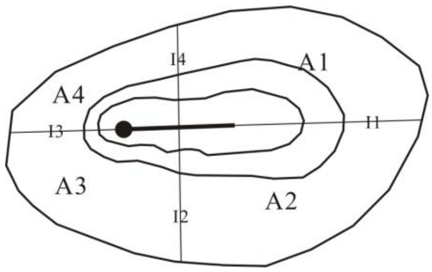


Figure 2.1. The four-area elliptical isoseismal of Wenchuan earthquake (Yang and Luo, 2010a)

(2) For a site between of arbitrary base PGA isoseismal curve i and i+1, the intercept of PGA acceleration isoseismal curve passing through the site at arbitrary axis h could be expressed using the formula below:

$$L_h(k) = L_{i,h} + (L_{i+1,h} - L_{i,h}) \cdot k \quad (2.1)$$

where, $L_h(k)$ is intercept of the PGA isoseismal curve at axis h; $L_{i,h}$ and $L_{i+1,h}$ are intercepts of the base PGA isoseismal curve i and i+1 at axis h respectively; k is a variate between 0 and 1.

For a site on arbitrary area j with semi-major axis b and semi-minor axis c, a quartic equation in which k is unknown is deduced as following based on elliptic equation:

$$\frac{x_j^{\,2}}{L_b(k)^2} + \frac{y_j^{\,2}}{L_c(k)^2} = 1 \quad (2.2)$$

where, $L_{b(k)}$ and $L_{c(k)}$ are intercepts of the PGA isoseismal curve at b and c respectively; x_j and y_j are projection lengths of the site at b and c respectively.

The intercepts of the PGA isoseismal at four axes could be obtained by solving the Eqn. 2.2 and taking the solution into Eqn. 2.1.

(3) Fit PGA attenuation relationships along four directions.

2.2. Six-area Elliptical Model

Actually, the isoseismal curves of Wenchuan earthquake with a long fault approximates one straight line in the adjacent area, which is near the mid-parts of the fault, and it approximates ellipse at ends of the fault, so Yang and Luo (2010b) divided the epicentral area into six parts and it was named six-area elliptical model. Unlike four-area elliptical model, two lines which are perpendicular to fault and pass through the epicenter and the other end of fault respectively are used as minor axes in six-area elliptical model (see Fig. 2.2). It is still assumed that intercepts of some PGA isoseismal curves at six axes are equal to intercepts of intensity isoseismal curves at six axes. If we ignored the characteristic of A2 area or A5 area, the six-area elliptical model would be changed into the four-area elliptical model. If sites located in A2 area or A5 area, the value of k can be calculated from the equation below:

$$\frac{y - L_d(k)}{x} = \frac{L_e(k) - y}{d_F - x} \quad (2.3)$$

where, $L_{d(k)}$ and $L_{e(k)}$ are intercepts of the PGA isoseismal curve at the semi-minor axis starting at the epicenter and the other end of fault respectively; d_F is the length of fault; x and y are projection lengths of the site at minor axis and fault starting at the epicenter.

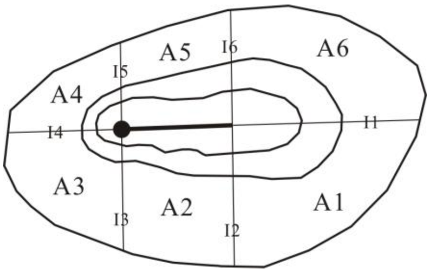


Figure 2.2. The six-area elliptical isoseismal of Wenchuan earthquake (Yang and Luo, 2010b)

2.3. "Mapping Circle" Model

As discussed above, circle model is inaccurate for predicting PGA of large earthquakes, and the forms of four-area elliptical model and six-area elliptical model are complex. We propose the "mapping circle" model, in which the fault of Wenchuan earthquake is compressed to epicenter and the PGA isoseismal is compressed to one circle. The intercept of isoseismal at semi-minor axis in footwall is defined as "mapping epicentral distance". As shown in Fig. 2.3, in fact the intercept at axis I3 in six-area elliptical model is chosen as "mapping epicentral distance", because in this direction the effect of fault-rupture directivity and hanging wall is the least.

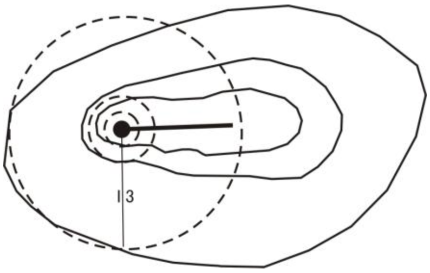


Figure 2.3. The "mapping circle" isoseismal of Wenchuan earthquake

Because of the special shape of isoseismal curves of Wenchuan earthquake, six-area elliptical model is used to map the "mapping epicentral distance". In fact, the isoseismal map of Wenchuan earthquake is different from that of any other earthquake even if it occurs in the same zone with the same magnitude, so the six-area model is not efficient in every case. We need continue to study way of mapping, because it is the key of enlarging application of "mapping circle" model.

3. RESULT AND ANALYSIS

Based on 216 PGA records of Wenchuan earthquake recorded at hard soil and rock sites, we analyzed four acceleration attenuation relationship using circle model and three models respectively. The four regression models are shown as below:

$$\ln Y = A_0 - B_0 \cdot \ln\left(R + R_0\right) \tag{3.1}$$

$$\begin{cases} \ln Y = A_1 - B_1 \cdot \ln\left(R_1 + R_0{}^1\right) \\ \ln Y = A_2 - B_2 \cdot \ln\left(R_2 + R_0{}^2\right) \\ \ln Y = A_3 - B_3 \cdot \ln\left(R_3 + R_0{}^3\right) \\ \ln Y = A_4 - B_4 \cdot \ln\left(R_4 + R_0{}^4\right) \end{cases} \tag{3.2}$$

$$
\begin{cases}
\ln Y = A_1 - B_1 \cdot \ln\left(R_1 + R_0{}^{1}\right) \\
\ln Y = A_2 - B_2 \cdot \ln\left(R_2 + R_0{}^{2}\right) \\
\ln Y = A_3 - B_3 \cdot \ln\left(R_3 + R_0{}^{3}\right) \\
nY = A_4 - B_4 \cdot \ln\left(R_4 + R_0{}^{4}\right) \\
nY = A_5 - B_5 \cdot \ln\left(R_5 + R_0{}^{5}\right) \\
nY = A_6 - B_6 \cdot \ln\left(R_6 + R_0{}^{6}\right)
\end{cases} \tag{3.3}
$$

$$
\ln Y = A_m - B_m \cdot \ln\left(R_m + R_0{}^{m}\right) \tag{3.4}
$$

where, Eqn. 3.1 is circle model, Eqn. 3.2 is four-area elliptical model, Eqn. 3.3 is six-area elliptical model, Eqn. 3.4 is "mapping circle" model; Y in gal is PGA; R_i in km is epicentral distance or intercept of PGA isoseismal at axis or "mapping epicentral distance"; $R_0{}^i$ in km is saturated distance with least variance from circulatory regression analysis for the relationship equation itself; and A_i and B_i are parameters obtained from the regression process.

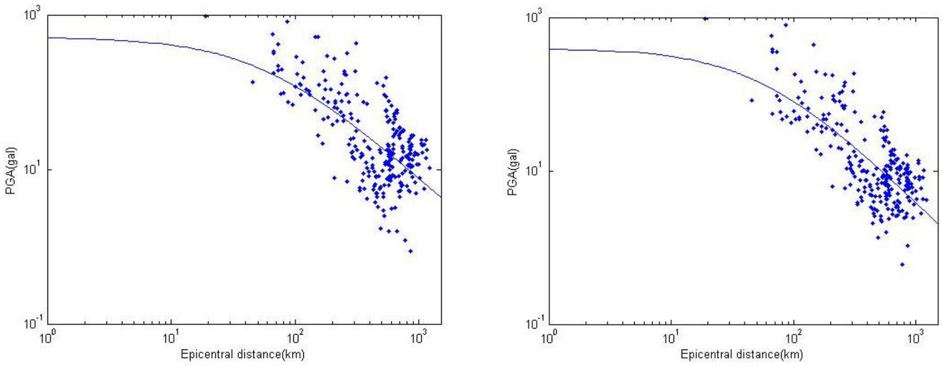
Table 3.1. Horizontal regression coefficient and variance

		A_i	B_i	$R_0{}^i$	$B_i/R_0{}^i$	$\sigma^2_{\ln Y}$
Circle model		12.06	1.44	57	0.025	0.93
Four-area elliptical model	I1	17.99	2.33	103	0.022	0.49
	I2	14.14	1.83	45	0.040	
	I3	12.13	1.54	25	0.062	
	I4	14.37	1.87	47	0.040	
Six-area elliptical model	I1	20.22	2.66	145	0.018	0.48
	I2	14.96	1.95	59	0.033	
	I3	14.01	1.83	46	0.040	
	I4	12.98	1.68	35	0.048	
	I5	11.36	1.45	20	0.073	
	I6	12.99	1.68	35	0.048	
"Mapping circle" model		12.91	1.65	46	0.036	0.46

Table 3.2. Vertical regression coefficient and variance

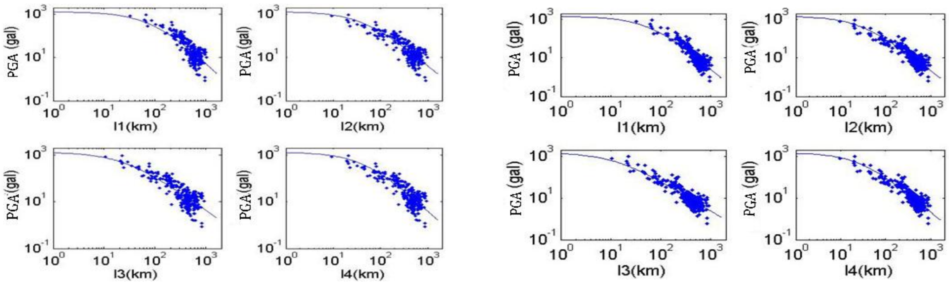
		A_i	B_i	$R_0{}^i$	$B_i/R_0{}^i$	$\sigma^2_{\ln Y}$
Circle model		12.42	1.59	57	0.028	0.75
Four-area elliptical model	I1	17.35	2.35	73	0.032	0.34
	I2	13.15	1.78	27	0.066	
	I3	11.05	1.47	13	0.113	
	I4	13.32	1.81	28	0.065	
Six-area elliptical model	I1	19.28	2.63	106	0.025	0.34
	I2	13.68	1.86	36	0.052	
	I3	12.61	1.72	26	0.066	
	I4	11.81	1.60	20	0.080	
	I5	10.53	1.43	12	0.119	
	I6	12.11	1.65	22	0.075	
"Mapping circle" model		11.61	1.56	26	0.060	0.33

The table 3.1 and table 3.2 show us that the variances of three acceleration attenuation models introduced in this paper are smaller than the circle attenuation model, six-area elliptical model and "mapping circle" model are especially better. As shown in Fig. 3.1, discreteness of circle model is larger than the suggested three models obviously. $B_i/R_0{}^i$ is defined as attenuation rate, which reflects attenuation velocity of ground motions in near field. Attenuation rate of circle model, an average value from every direction, is wrong in the fault-rupture directivity (I1 direction in four-area elliptical model and six-area elliptical model shown in Fig. 2.1 and Fig. 2.2). Because the effect of fault-rupture directivity and hanging wall on PGA in the footwall is the least, the attenuation rate in footwall is smaller than that in hanging wall. And it proves that the choice of using I3 as mapping axis in the "mapping circle" model is reasonable.



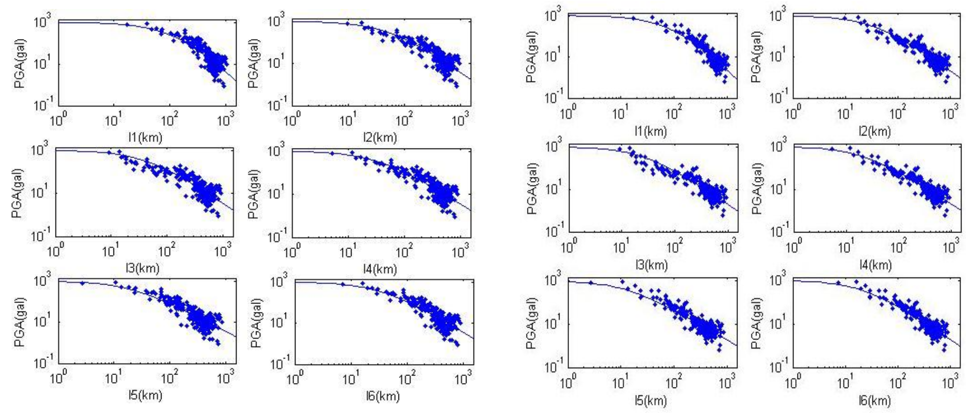
Horizontal Vertical

Attenuation relationships of circle model



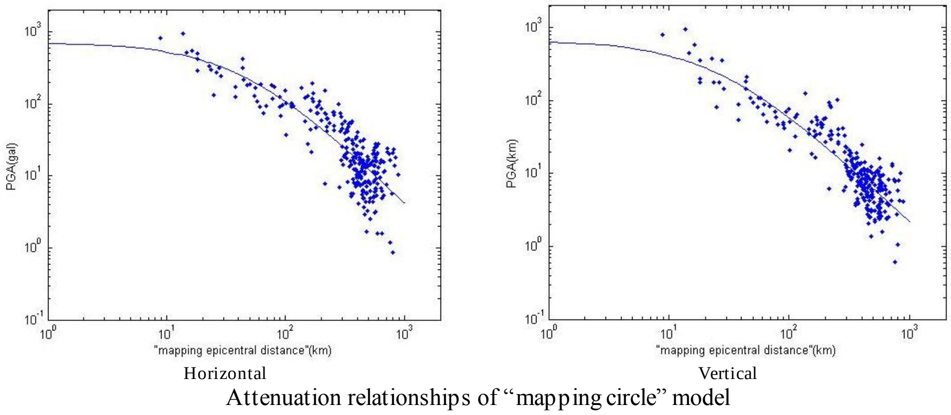
Horizontal Vertical

Attenuation relationships of four-area elliptical model (Yang and Luo, 2010a)



Horizontal Vertical

Attenuation relationships of six-area elliptical model (Yang and Luo, 2010b)



Horizontal Vertical

Attenuation relationships of "mapping circle" model

Figure 3.1. Comparison of attenuation relationships of different models with scatter diagram

4. DISCUSSION AND CONCLUSION

Considering the effect of fault-rupture directivity and hanging wall on acceleration, we propose three PGA attenuation models which are four-area elliptical model, six-area elliptical model and "mapping circle" model, based on the assumption that there is a blurred proportional relationship between PGA and seismic intensity for the same earthquake.

Based on 216 PGA records of Wenchuan earthquake recorded at hard soil and rock sites, we use the suggested three attenuation models to simulate the PGA distribution in near field respectively. Then we compare the simulation results with circle model result. The results show that the three models we introduced are much more accurate than the circle model.

The next step we will study how to use the suggested model to predict the ground motion distribution in near field for future large earthquakes.

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