The Ground Motion Attenuation Relation for the Mountainous Area in Sichuan and Yunnan

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SUMMARY:
In 2007, after the National Strong Motion Observation Network System (NSMONS) of China was put into operation, a lot of strong motion data has been got, especially in the quake-prone mountainous area in Sichuan and Yunnan. To August 20, 2011, in the dense network region in Sichuan and Yunnan, 14 main shocks that magnitude is larger than Ms5.0 occurred that include Wenchuan Ms8.0. In these earthquakes, NSMONS obtained observation recordings in multi-stations.
Basing on strong motion observation data in the Sichuan-Yunnan region, this paper constructs the ground motion attenuation relations in this region. In this paper, the ground motion parameters are taken as the geometric mean of two horizontal earthquake motions. As in the observation data, a lot were obtained in the aftershocks of Wenchuan earthquake, for understanding the inflection of data of Wenchuan earthquake, this paper uses three statistical methods: 1. without weighting; 2. weighting except Wenchuan aftershocks data; 3. without weighting and Wenchuan aftershock data. The results show three statistics are quite different.
In this paper, we also compares our results with previous results in same regions. It shows that there is a certain difference between these results. Due to our statistics results based on the observation data of Sichuan-Yunnan quake-prone mountainous area, therefore, our results can better reflect actual ground motion attenuation of the Sichuan-Yunnan mountainous region.

Keywords：Strong Motion Attenuation Relation, Strong Motion Station Network, the Mountainous Area in Sichuan and Yunnan, moderate Earthquake, Observation Recordings

1. INTRODUCTION

The Chinese Mainland is a destructive earthquake-prone area. But due to very few strong motion stations, it is very small that the number of strong motion recordings gained in the Chinese Mainland, especially in near fields. So while to develop the strong motion attenuation relationships in Chinese Mainland, the researchers often need to make use of the data captured in other areas(Hu Y.X.，etc.,1984;Cui J.W.,etc.,2006). The state being short of strong motion observation data is effectively improved after the nation strong motion observation network system of China(NSMONS) was constructed in the 15th Five-Year Plan of China, especially in the quake-prone Mountainous Area of Sichuan-Yunnan. After NSMONS was put into operation, a lot of destructive earthquakes, such as the 2007 Ms6.6 Lao, 2007 Ms6.4 Ninger, 2008 Ms5.9 Yingjiang, 2008 Ms6.1 Panzhihua, 2009 Ms6.0 Yaoan,2009 Ms5.0 Binchuan, 2011 Ms7.2 Burma and so on, have been occurred in Sichuan-Yunnan and its neighbouring area, and a large number of recordings were captured. Especially in 2008 M8.0 Wenchuan earthquake, over 400 stations of NSMONS captured mainshock recordings on free field(Li X.J.,etc. , 2008), and ten thousand aftershock recording that the magnitudes are between Ms3.0 and Ms6.4 were also captured with permanent and mobile strong motion stations in quake zone(Li X.J.,etc. , 2008,2009).

For the most earthquakes that occurred in Sichuan-Yunnan mountainous area since 2007 are moderate earthquakes that magnitude is less than Ms6.4, in this paper, we present the strong motion attenuation relationships of moderate earthquakes.

1. DATA

1.1 Data Base

We select data from the recordings captured in Sichuan-Yunnan mountainous area on the following criterion: (1) epicenter distance are less 110km； (2) magnitude is large than or equal to 4.5; (3) Two horizontal components are complete; (4) Accelerograms have a PGA of 0.01g at least for one horizontal component. Table 1 is the situation of selected recordings. We get the velocity time-history from integration of a accelerogram.

Table 1. the situation of recordings applied in this paper

Earthquake	Magnitude of mainshock	Time of earthquake	Numbers of recordings
Ninger	6.4	3,June,2007	17
Burma	5.7	23, June,2007	3
Yingjiang	5.8	21, August,2008	20
Panzhihua	6.1	30, August,2008	29
Yaoan	6.0	10,July, 2009	46
Binchuan	5.0	2,November,2009	10
Wenchuan*	8.0	12,May,2008	837

* without includes the recordings of mainshock.

There are 962 recordings in Table 1, but the vast majority of the data are from Wenchuan aftershock . The regression analysis basing on these data will mainly reflect seismogeology characteristics of Wenchuan earthquake area if without any special processing. In this paper, we performed regression in three methods: 1) Unweighting regression; 2) Weighting regression but unweighting for Wenchuan aftershock data; 3) Regression Without Wenchuan aftershock data. Through three regression methods, we can compare and analyze the influence of Wenchuan aftershock data.

Fig.1 is distribution of the recordings on the magnitude-distance. In these recording, we can see the recordings that the magnitude is less than 4.8 are most abundant and evenly distribute among epicenter distance less than 110km. With the growth of the magnitude, the recordings that epicenter distance is less than 10 reduce or lack。 Fig.2 is the same with Fig.1 but without the aftershock data of Wenchuan earthquake. It can be seen that the recordings are evenly distributed in less than 110km although the number of recordings is lesser.

1.2 The Ground Motion Parameters

The ground motion parameters in this paper include the peak ground acceleration(PGA),the peak ground velocity(PGV) and the 5%-damped pseudo-spectral acceleration (PSA). For two orthogonal horizontal components, we use their geometric mean, that is:

$$Y_{Geomean} = (Y_{GEW} \times Y_{NS})^{1/2} \tag{1}$$

Where $Y_{Geomean}$ is the geometric mean the two horizontal components, and Y_{GEW}, Y_{NS} are absolute value of East-west or North-south components respectively.

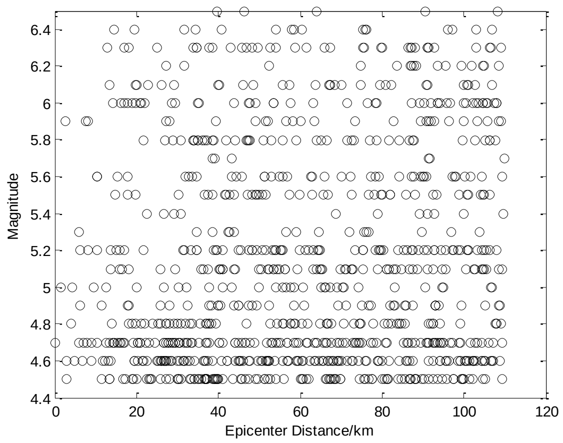

Figure 1. Magnitude-Epicenter Distribution of The recordings applied in this paper(o: recordings)

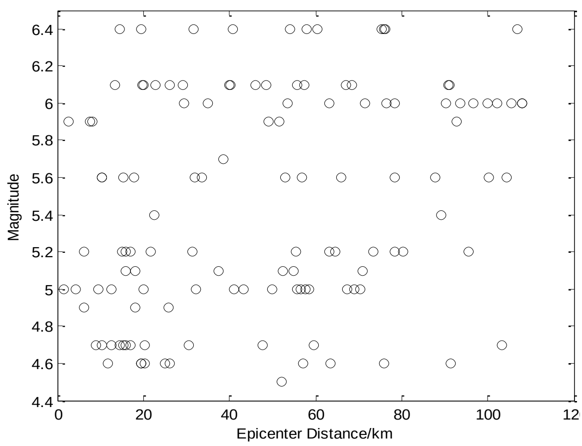

Figure 2. Magnitude-Epicenter Distribution of The recordings applied without aftershock recordings of Wenchuan earthquake(o: recordings)

2. GROUND MOTION ATTENUATION MODEL

This paper use function (2) (McGuire,1978; Douglas, 2001）for our regression analysis.

$$\lg(Y) = c_1 + c_2 M + c_3 \lg(R + R_0) + c_4 S + \sigma \tag{2}$$

where, Y ground motion parameters, M earthquake magnitude, c_1、c_2、c_3、c_4 regression coefficient, R_0 near field saturation factor of ground motion amplitude, S site factor, for soil S=1， and rock S=0, σ standard deviation.

3. REGRESSION ANALYSIS AND RESULTS

A genetic hybrid algorithm that combines genetic algorithm and nonlinear unconstrained least-square optimization are used to regress coefficients of function(2). While regression, first set R_0=15km, after getting coefficients of function (2), let R_0 changes in 5~30km, search R_0 that minimums standard deviation. Regression will be performed with three method.

3.1 Unweighted Regression

Fig.3 shows that the standard deviation of attenuation relations changes with R0. It shows for

PGA,PGV and PSA that the most standard deviations will be minimum while R0 is in 6km ~ 15km. Here let R0 =10km. Table 1 is the some coefficients and standard deviations of attenuation relationships while R0 = 10km.

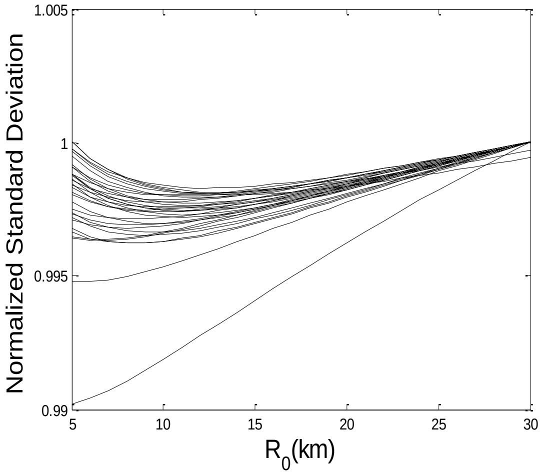

Figure.3. Normalization standard deviation of attenuation relationship changes with R_0(5~30km)

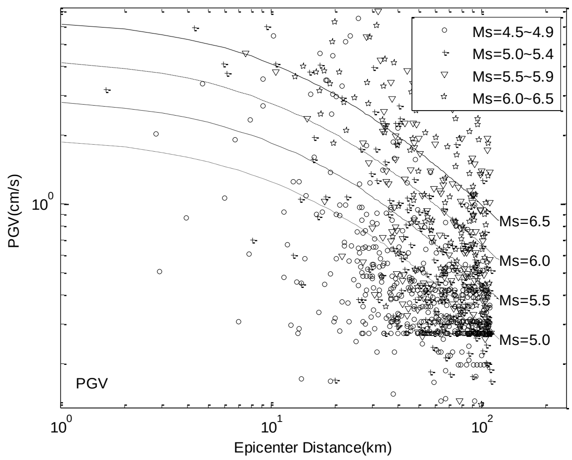

Figure.4. The attenuation relationships of PGV(4 curve) and the PGVs from recordings

Table 1 Unweighted Regression Coefficients and standard deviations of attenuation relations

Periods/s	C1	C2	C3	C4	σ
PGV	-0.1864	0.3448	-0.9958	-0.0159	0.2823
PGA	1.8207	0.3506	-1.2775	-0.1370	0.3445
0.04	2.0619	0.3479	-1.2720	-0.2320	0.3746
0.1	2.2603	0.3257	-1.2361	-0.1124	0.3716
0.5	0.5144	0.5420	-1.2988	-0.0438	0.4016
1	-0.4878	0.5905	-1.2567	0.0055	0.3651
6	-1.1955	0.4518	-1.2860	-0.0316	0.3307

Fig.4~Fig.6 is PGV, PGA and PSA(T＝0.1s) from attenuation relationships and observation recordings while the earthquake magnitudes are equal to Ms5.0, Ms5.5, Ms6.0, Ms6.5 respectively.
Fig.7 ~ Fig.8 show that the residual error of the attenuation relationships of PGA, PGV change with epicenter distances. Here, the residual error $\varepsilon = (Y_{OBS} - Y_{PRE})$, where Y_{OBS} is observation and Y_{PRE} is calculation from the attenuation relationships.

3.2 Weighted Regression

Here, weighted regressions are performed and data is weighted except Wenchuan aftershock data to reduce the influence of Wenchuan aftershock data. Weighting of data are performed through repeated use of data.
Fig.9 shows that the standard deviation of attenuation relationships with weighted regression changes with R_0. It can be seen for PGA,PGV and PSA that the most standard deviations will be minimum while R_0 is in 8km~13km(centering around 8km). Here let R_0=8km. Table 2 is the coefficients and standard deviations of attenuation relations whileR_0= 8km.

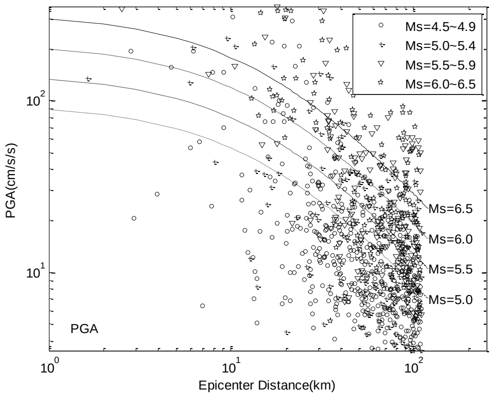

Figure 5. The attenuation relationships of PGA(4 curve) and the PGAs from recordings

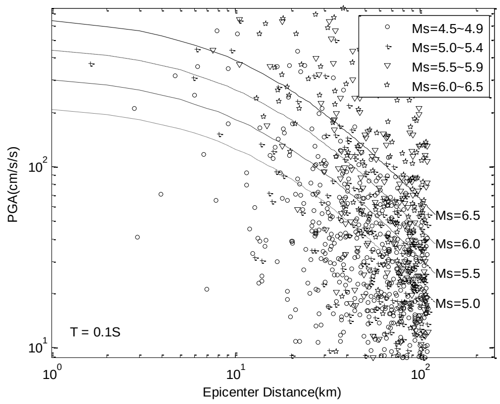

Figure 6 The attenuation relationships of PSA(curves, Damping 5%，T=0.1S) and the PSAs from recordings

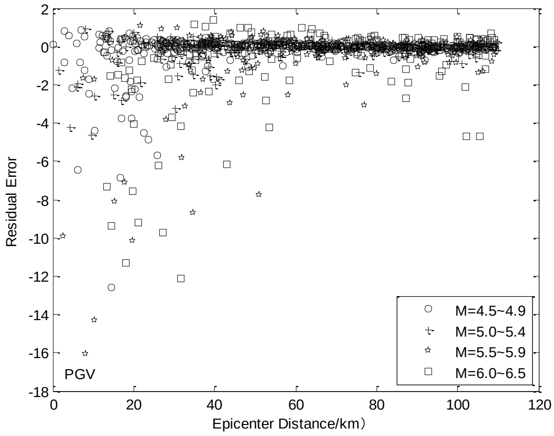

Figure 7. The residual error of PGV attenuation relationships change with epicenter distances

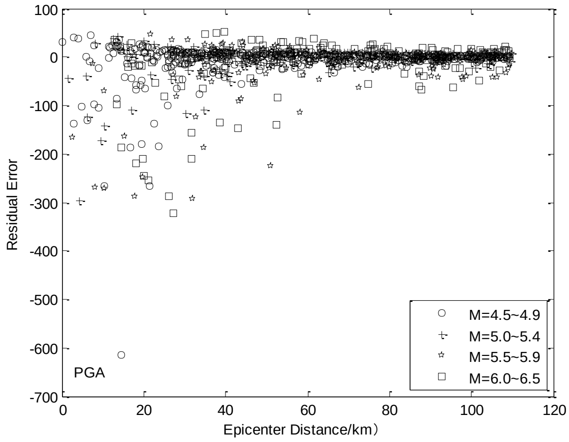

Figure 8. The residual error of PGA attenuation relationships change with epicenter distances

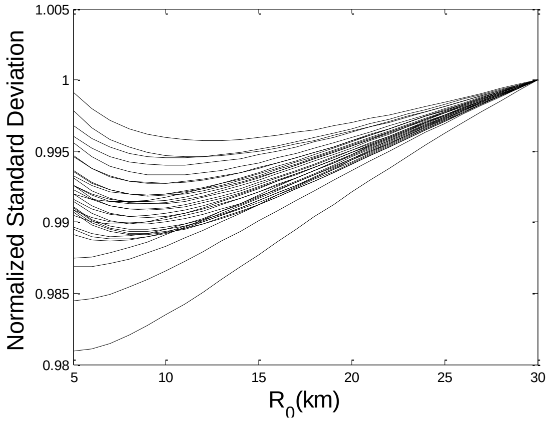

Figure 9. Normalization standard deviation of attenuation relation changes with R0(5~30km)

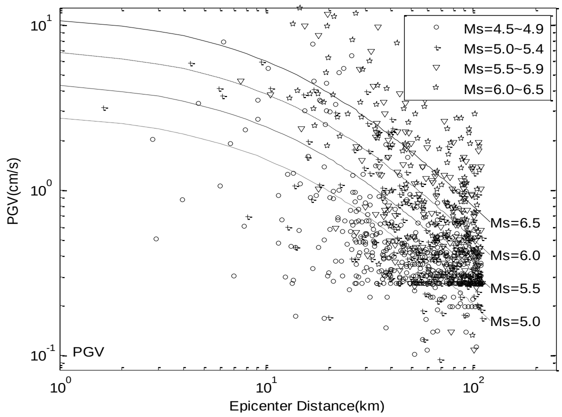

Figure 10. The attenuation relationships of PGV(curves) and the PGVs from recordings

Fig.10～Fig.12 is PGV, PGA and PSA(T＝0.1s) from attenuation relationships and recordings while the earthquake magnitudes are equal to Ms5.0, Ms5.5, Ms6.0, Ms6.5 respectively.

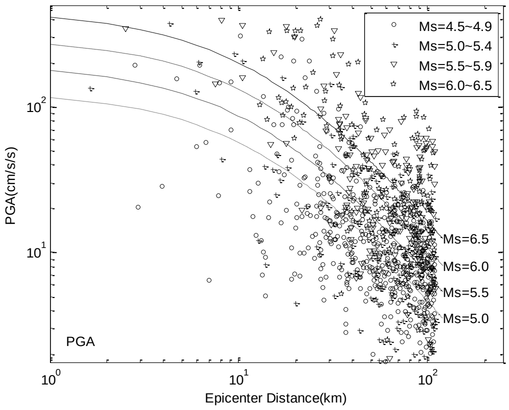

Figure 11. The attenuation relationships of PGA(curves) and the PGAs from recordings

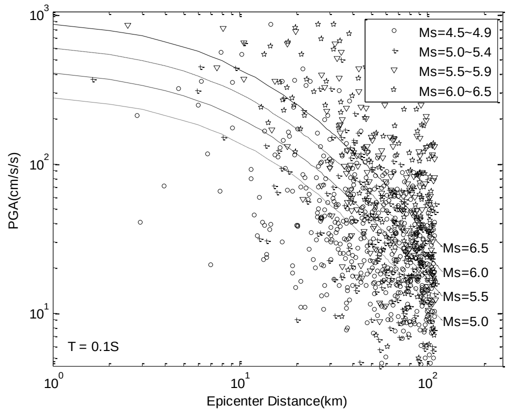

Figure 12. The PSA attenuation relationships (curves) and the PSAs from recordings(Damping 5%, T = 0.1S)

Table 2. Weighted regression coefficients and standard deviations of attenuation relationships of PGV, PGV and PSA

Period/s	C1	C2	C3	C4	σ
PGV	0.2589	0.3962	-1.4182	0.0384	0.3279
PGA	2.4911	0.3647	-1.7654	-0.0575	0.3902
0.04	2.8539	0.3587	-1.8278	-0.1606	0.4199
0.1	3.0193	0.3287	-1.7409	-0.0722	0.4193
0.5	1.2018	0.5365	-1.7012	0.0935	0.3945
1.0	0.0121	0.5761	-1.5195	0.1540	0.3728
6.0	-0.6345	0.4588	-1.6721	0.0827	0.3440

Fig.13 ~ Fig.14 show that the residual error ε of the attenuation relationships of PGA, PGV change with epicenter distance.

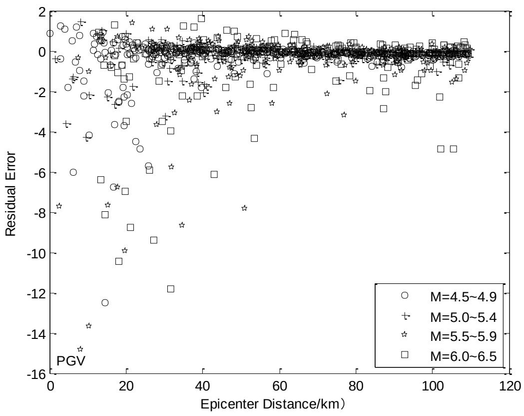

Figure 13. The residual errors of PGV attenuation relationships change with epicenter distance

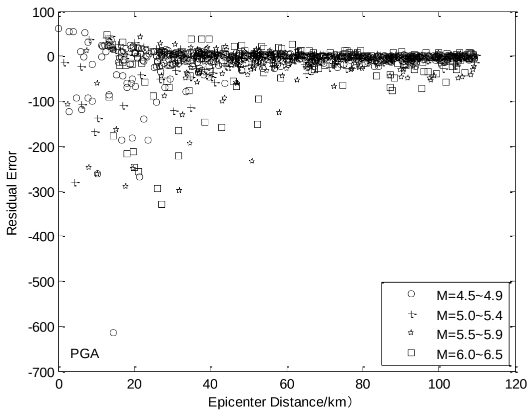

Figure 14. The residual errors of PGA attenuation relationships change with epicenter distance

3.3 Regression without Wenchuan aftershock data

Here, Regressions are performed without Wenchuan aftershock data. Fig.15 shows that the standard deviation of attenuation relationships changes with R_0 while getting rid of Wenchuan aftershock data. We can see for PGA,PGV and PSA that the most standard deviations will be minimum while R_0 is in 10km～20km. Here let R_0 =15km. Table 3 is the coefficients and standard deviations of attenuation relationships while R_0= 15km.

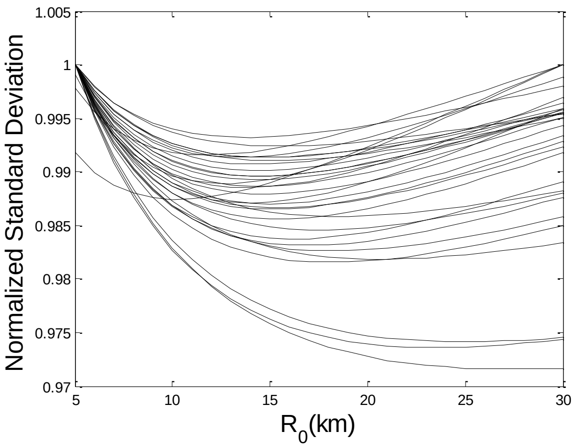

Figure 15. Normalization standard deviation of attenuation relationships changes with R_0（5~30km）

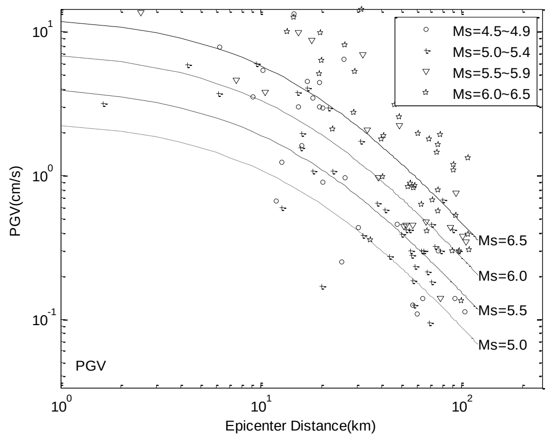

Figure 16. The attenuation relationships of PGV(curves) and the PGVs from recordings

Table 3. Weighted regression coefficients and standard deviations of attenuation relationships of PGV, PGV and PSA

Period/s	C1	C2	C3	C4	σ
PGV	0.6560	0.4870	-2.0028	0.2318	0.3414
PGA	2.7831	0.4956	-2.6029	0.4220	0.3546
0.04	3.1459	0.5211	-2.7985	0.3572	0.3568
0.1	3.3380	0.4913	-2.6851	0.3551	0.3677
0.5	1.9523	0.4841	-2.0943	0.4620	0.3500
1.0	0.7126	0.4686	-1.6812	0.4912	0.3421
6.0	-0.1941	0.4881	-2.2081	0.5085	0.3175

Fig.16～Fig.18 is PGV, PGA and PSA(T＝0.1s) from attenuation relationships and recordings while the earthquake magnitudes are equal to Ms5.0, Ms5.5, Ms6.0, Ms6.5 respectively.

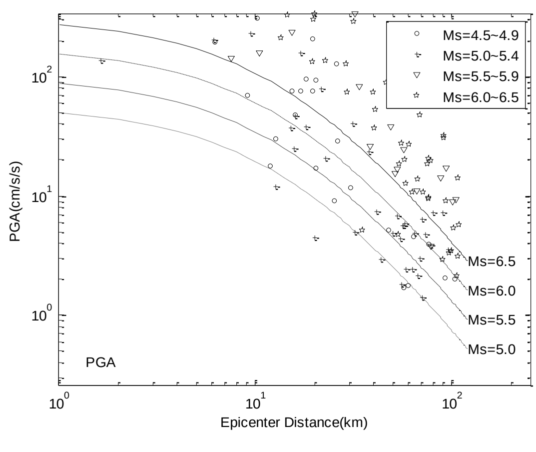

Figure 17. The attenuation relationships of PGA(curves) and the PGAs from recordings

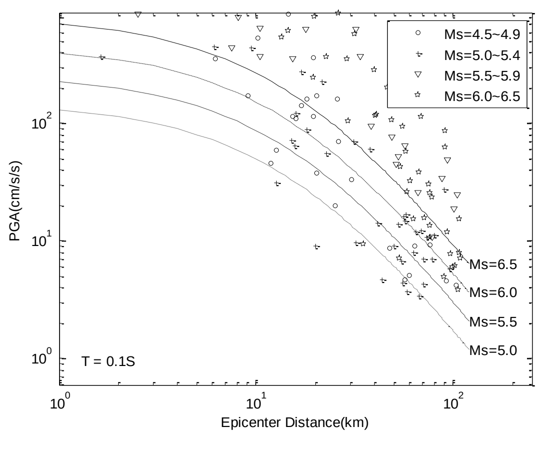

Figure 18. The attenuation relationships of PSA(curves) and the PSAs from recordings(damping: 5%，T=0.1S)

Fig.19 ~ Fig.20 show that the residual error ε of the attenuation relationships of PGA, PGV change with epicenter distance.

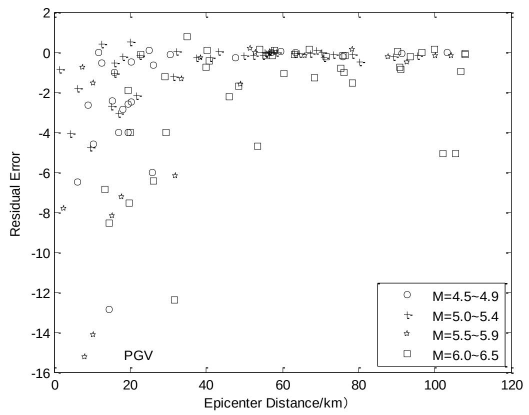

Figure 19. The residual errors of PGV attenuation relationships change with epicenter distance

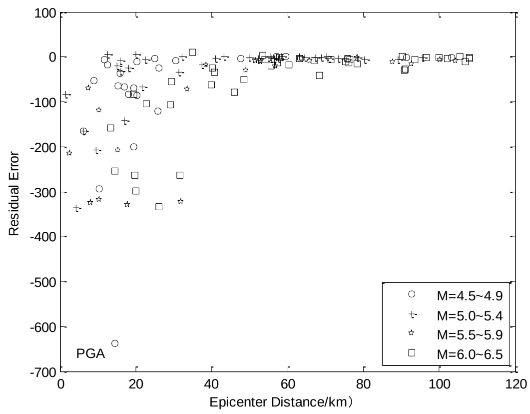

Figure 20. The residual errors of PGA attenuation relationships change with epicenter distance

4. DISCUSSION AND CONCLUSION

4.1 The Comparison Of Attenuation Relationships

4.1.1. The comparisonof three attenuation relationships in this paper

For three group attenuation relationships from three regression methods, Fig.21~Fig.24 show the their comparisons while the earthquake magnitudes are Ms5.5 and Ms6.5 respectively. We can see that their differences are large. In three group relationships, the relationships from weighting regression give results that are largest in most cases. On attenuation curve appearance, results from weighting regression and regression without Wenchuan aftershock data are similar, and results from Unweighted regression attenuates the slowest. For PGV, results of second and third groups are similar, but for PGA, results from third group are smaller and attenuations are the slowest.

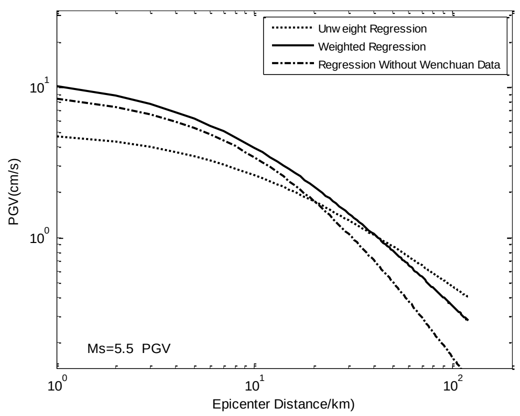

Figure 21. Comparison of three PGV attenuation relationships（Ms5.5）

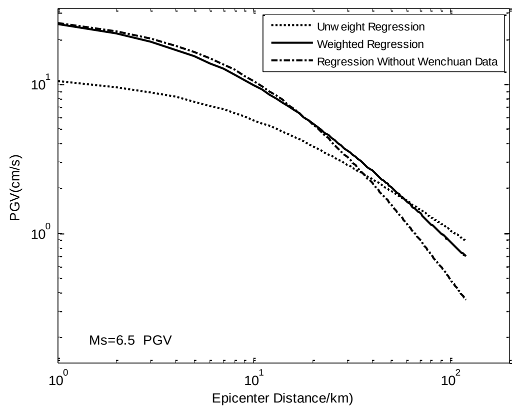

Figure 22. Comparison of three PGV attenuation relationships（Ms6.5）

As a comparison with the observation data, table 4 gives the comparison results of three group attenuation relationships with Ninger Ms6.4 earthquake. The numerical values in table are the absolute mean value of the residual error between the observation data and three attenuation relations respectively. We can see that the weighted statistical regression gives the best results. We will use the weighted statistical regression results later.

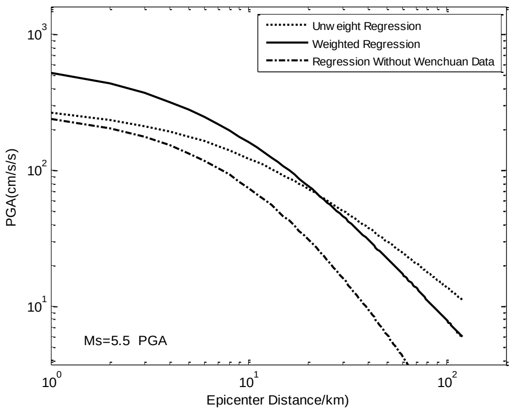

Figure 23. Comparison of three PGA attenuation relationships（Ms5.5）

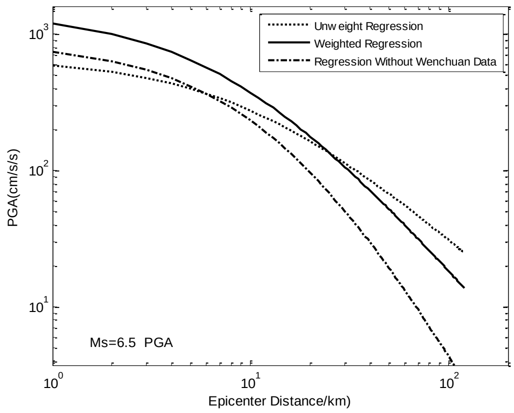

Figure 24. Comparison of three PGA attenuation relationships（Ms6.5）

Table 4. The mean residual error of three group attenuation relationships respectively with the observation data in Ninger Ms6.4 earthquake

Periods	Unweighted Regression	Weighted Regression	Regression Without Wenchuan Data
PGV	1.4	1.2	1.2
PGA	34.9	27.5	32.6
0.04	61.6	47.5	35.9
0.1	75.3	59.3	55.8
0.5	40.9	39.2	55.7
1.0	8.7	8.6	12.3
6.0	0.2	0.2	0.2

4.1.2. The comparison of this paper results and other attenuation relationship in Yunnan

Fig.25 shows the comparison of this paper results and a PGA attenuation relationship given by Cui jianwen, etc (2006) for the west of Yunnan. We can see that the difference is significant. For basing on the more plentiful observation data, this paper results are more reasonable.

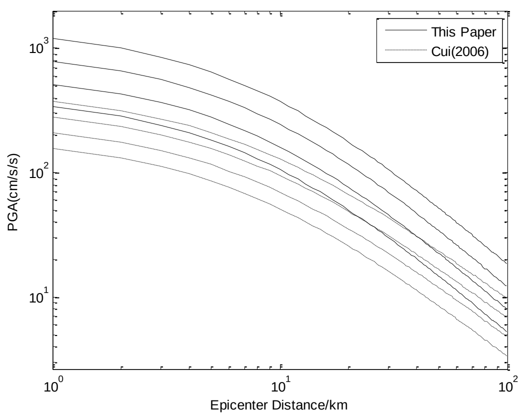

Fig.25 The comparison of this paper results and PGA attenuation relationship in west of Yunnan given by Cui(2006)(for curves in fig.40, from top to down, magnitudes are respectively Ms5.0, 5.5,6.0,6.5)

4.2. Characteristics of strong motion attenuation in Sichuan-Yunnan Mountainous Area

For function (2), the ground motions on soil site is c_4 multiple on rock site, and table 1,2,3 show that some c_4 are positive, but some negative for different periods. So in different periods, the ground motions on soil site may be larger than on rock site, but may be smaller.

4.3 Residual analysis

The residual error figures show that the discrete level of observation data reduces with the increase of epicenter distance. It means that the discrete level of ground motions in near field is higher. The reasons are that the ground motions are richer in high-frequency and the high-frequency ground motions are more randomness. In addition, the near-field ground motion is not only the response of seismic waves on the surface, but also includes the direct impact of the fault, the impact of the fault also is strong in randomness.

4.4 Existing problems

For the observation site conditions are not particularly clear, the site effects corrections are not performed, and only the site is divided into the bedrock and soil. Although it cannot reflect the complex site influence on ground motions, the residual distribution shows that the result are realistic.

4.5 Conclusion

Basing on rich ground motion data, this paper present a ground motion attenuation relation. Due to the observational data are catch mostly in the mountains, the results can be used for seismic safety analysis in the mountainous area. Error analysis shows that the results in this paper can reflect better the variation of realistic ground motion. The contrast with the results of previous studies show a greater difference, but this paper results based on the statistics of the richer realistic data, it should be closer to reality.

For the observation site conditions is unclearly known, this paper does not correct the site effects. In the future, it should be done to use station site characterization data to amend this paper results.

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