COMPARISON AND ANALYSIS OF ATTENUATION RELATIONSHIPS OF NEAR-FAULT HORIZONTAL PEAK GROUND ACCELERATION AND VELOCITY

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ABSTRACT:
In the recent years, more complicated failure characteristics appeared in the near-fault region of earthquakes and many attenuation relationships of some parameters that characterized these region were brought forward, which intended to provide some references for seismic hazard analysis and structure design. These attenuation relationships are different from each other because different earthquake records were adopted and different effecting factors were considered during the process of regression. So, which one is suitable for the future application becomes a question. In order to solve this problem, some representative attenuation relationships of near-fault horizontal peak ground acceleration (PGA) and velocity (PGV) are selected and the results calculated from them and those recorded ones are compared and analyzed. Then some reasonable attenuation relationships are recommended, which are both close to the real PGA or PGV and the other calculated ones. Also, it is found that these attenuation relationships are useful when the distance surpass their original effective scope to some extend. Finally, some further research should be done is expected.

KEYWORDS:
Near-fault; PGA; PGV; attenuation relationship

1. INTRODUCTION

In the recent years, many earthquakes happened in and abroad, such as the 1994 Northridge (Mw 6.7), the 1999 Kobe (Mw 7.2) and the 1999 Chi-chi (Mw 7.6) , caused large damage to city infrastructures , great economical loss and casualty. From these earthquakes, it was found that amplitude characteristic in the near-fault region is different from those in the far-field. So, many new near-fault attenuation relationships appeared (William B. J. etc 1981; McGarr, 1984; Fabio, S. etc 1987; Campbell K. W. 1989; Youngs etc., 1997; Huihua, H. 1998; Ambraseys, N. and Douglas, J. 2000; C. H. Yeh etc 2001. Campbell, K. W etc 2003; Guangbiao S. etc 2004; Qimin, F. etc 2004; Xile L. etc 2006; Sinan A. etc 2007; Hemei, Q., etc 2007), which intended to provide some references for seismic hazard analysis and structure design. These attenuation relationships are not the same because different earthquake records were adopted and different influencing factors were considered during the process of regression. So, which one is suitable for the future application becomes a question. It's meaningful to compare and analyze the existing PGA and PGV attenuation relationships and give some advice on how to select a reasonable one from them for future application.

2. INFLUENCING FACTORS OF ATTENUATION RELATIONSHIPS

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Attenuation relationships are often set up by restricting regression equations with the existing method. Generally, three kinds of influencing factors are considered in the regression equations: source character, propagation medium and site condition (Yuxian, H .1988）.

Source character was originally described by magnitude. Surface wave magnitude (Ms) and moment magnitude (Mw) was generally used in the attenuation relationships. Because if Mw=5-7.5, then Ms=Mw (Yuxian, H .1988）and almost all magnitudes selected in this study are in this scope, so Ms=Mw is adopted. Then, focal depth (d) and fault-type were found important to describe source character for near-fault ground motion, so some researchers considered these factors in the attenuation relationship (Guangbiao S. etc 2004; Qimin, F. etc 2004). Propagation media is often characterized in the attenuation relationship by site category. But unfortunately, there is no unified method to classify site conditions, Such as they are classified four kinds by the depth of overburden and mean shear wave velocity in China, four kinds in USGS according to mean shear velocity, and five kinds in NEHRP. If site conditions are classified in detail, the amount of records of each site will be not enough to be used in regression (Changhai, Z. 2005, Maosheng G. 2004). On the contrary, the accuracy of the result will be reduced. Considered comprehensively, site conditions are classified into three kinds in this study: firm soil, soil and soft soil. Two fault distances are generally used in attenuation relationship of near-fault ground motion. They are the closest distance to the projection of fault plane (Rp) and closest distance to the fault plane (Rr). In order to make the comparison and analysis work easily done, Rr and Rp was used in calculation respectively according to the attenuation relationship, but Rr was instead by the corresponding Rp in figure 1 and figure 2 if both of them could be found in the selected records.

3. SELECTION OF SEISMIC RECORDS

All the seismic records are selected from the “PEER Strong Motion Database” (http://peer.berkeley.edu/smcat /search.html). If PGA <0.05g, the errors come from measurement may be large. So only the records with PGA ⩾0.05g are selected. PGA is the mean value of the two horizontal components. There is no definite range for near-fault earthquake ground motions, but most researchers believe it should be within the scope of 30km (Rr or Rp). So all the records selected are in this scope. The amount distribution of the records according to the site classification is are follows: firm soil 219 pieces; soil 468 pieces and soft soil 111 pieces.

4. COMPARISON AND ANALYSIS OF ATTENUATION RELATIONSHIPS OF PGA

4.1. Attenuation Relationships of PGA

Different influencing factors were included in different attenuation relationships of near-fault horizontal PGA. Some of them were set up based on the attenuation relationships of far-field horizontal PGA, which only considered the influencing of magnitude, distance and site conditions. Others of them were added to some new special factors of near-fault ground motion, such as focal depth, fault types etc. Some representative attenuation relationships are listed in table 1 and each of them are named according to the corresponding author.

The parameters in the attenuation relationship of the original form are all changed to the same signals without changing their physical meaning: influencing factors of soil category (S, Sa and Ss)，for firm soil Sa=1, for soft soil Ss=1, else Sa=0 and Ss=0; influencing factors of fault type (F) ，hanging wall effect (Hw) and the rest signals, such as PGA, Ms, d Rr and Rp, have been mentioned above.

Table 1 Attenuation relationships of PGA

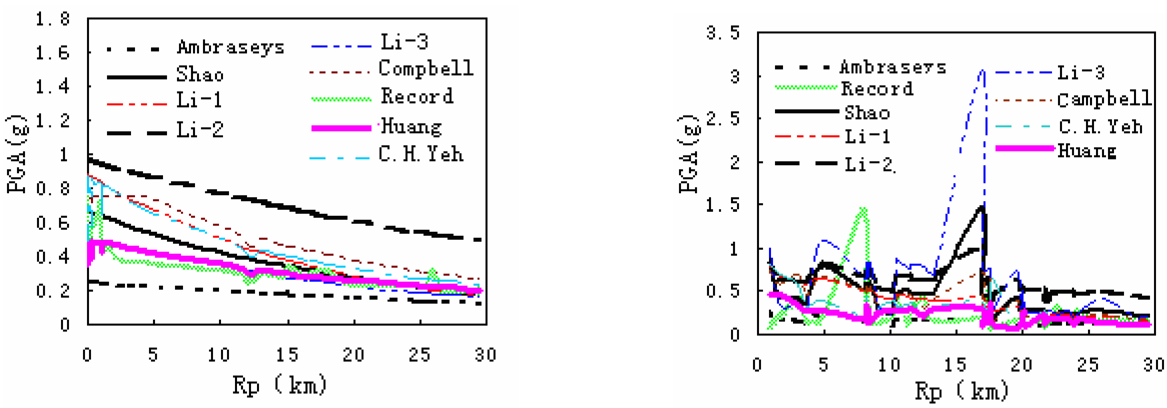
Attenuation relationships of PGA	Name
$\log_{10} PGA = -1.2581 + 0.5101Ms - 1.774\log(Rr + 0.39e^{(0.623Ms)})$	Huang
$\log PGA = -0.659 + 0.202Ms - 0.0238Rp + 0.020Sa + 0.029Ss$	Ambraseys

Table 1 Attenuation relationships of PGA (continued)

Attenuation relationships of PGA	Name
$\log PGA=\begin{cases}-1.358\log(Rr+1.58)-0.071Rr+1.404Mw+1.395 & \text{(china)} \\ -1.256\log(Rr+0.0312e^{0.855Mw})-0.0071Rr+1.075Mw+2.42 & \text{(Taiwan)}\end{cases}$	C. H. Yeh
$\log PGA=-4.033+f_1(Mw)-0.812\log(\sqrt{f_2(Mw,Rr,S)})+f_3(F)+f_4(S)+f_5(Hw,F,Mw,\ Rr)$ (corrected)	Campbell
$\log_{10} PGA=\begin{cases}1.4182+0.1923Mw-0.0194Rp-0.0057d & \text{firm soil} \\ 1.146+0.2302Mw-0.0115Rp-0.0055d & \text{soft soil} \\ 1.4209+0.1904Mw-0.0157Rp-0.003d & \text{soil}\end{cases}$	Shao
$\log PGA=\begin{cases}-0.8337+0.0926Mw-0.0562Rp & \text{firm soil} \\ -0.6587+0.0259Mw-0.0133Rp & \text{soil} \\ -1.4814+0.187Mw-0.0357Rp & \text{soft soil}\end{cases}$ strike-slip fault	Li-1
$\log PGA=\begin{cases}-1.4409+0.185Mw-0.023Rp & \text{firm soil} \\ -0.669+0.05Mw-0.0184Rp & \text{soil} \\ -0.0868+0.0212Mw-0.0568Rp & \text{soft soil}\end{cases}$ reverse fault	Li-2
$\log PGA=\begin{cases}-2.388+0.365Mw+0.327(Rp^2+10^2)^{0.5} & Mw<6.5 \\ -12.631+2.3Mw-1.259(Rp^2+10^2)^{0.5} & 6.5\le Mw<7.0 \\ -2.388+0.547Mw-0.65(Rp^2+10^2)^{0.5} & Mw\ge 7.0\end{cases}$ firm soil	Li-3
$\log PGA=\begin{cases}1.348+0.122Mw-1.33\log(Rp^2+10^2)^{0.5} & Mw<6.5 \\ -5.593+1.141Mw-1.1159\log(Rp^2+10^2)^{0.5} & 6.5\le Mw<7.0 \\ -7.066+1.14Mw-0.863\log(Rp^2+10^2)^{0.5} & Mw\ge 7.0\end{cases}$ soil	Li-3

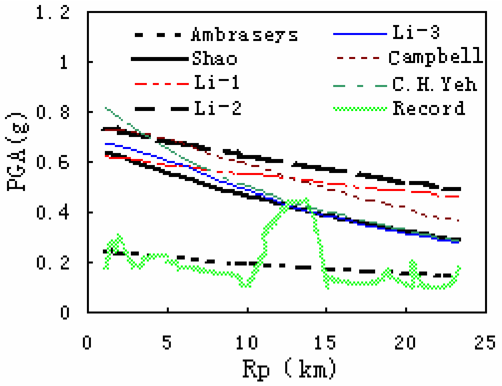
4.2. Comparison and Analysis of the Calculation Results and Recorded PGA

Figure 1 shows how PGA changes with fault distance (Rr or Rp) at different site conditions. “Record” represents those recorded PGA come from database. All the abscissa represents Rp except figure (f) for the records limitation. All curves in figure (a), (c) and (e) are gotten based on Chi-chi earthquake records, which reveals how PGA changes with Rp when magnitude is the same. Curves in the rest figures are gotten based on the other earthquakes around the world, which reveals how PGA changes with Rp or Rr when magnitudes are

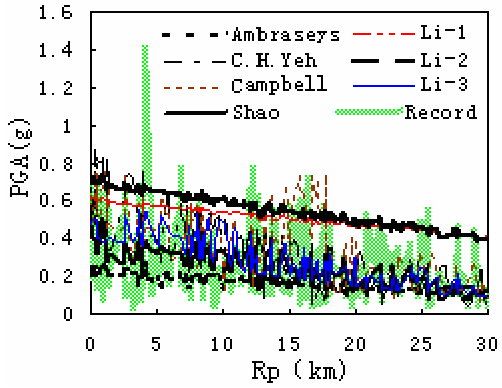


(a) Firm soil (Chi-chi earthquakes) (b) Firm soil (other earthquakes)

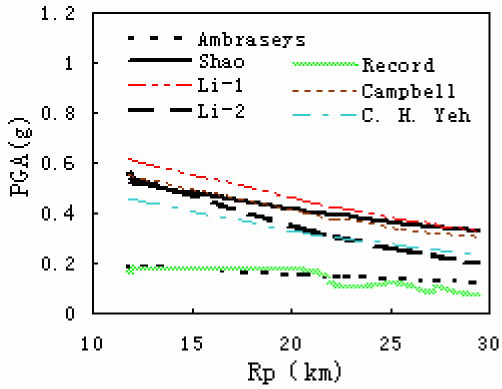
Figure 1 PGA versus Rp or Rr curves



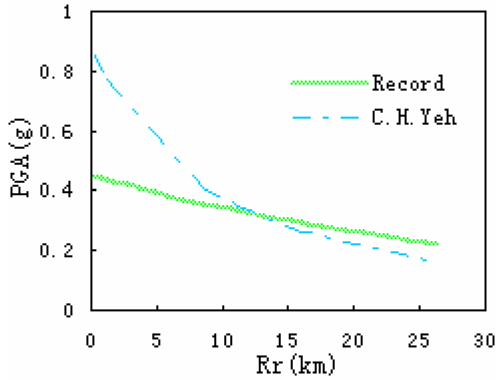
（c）Soil (Chi-chi earthquakes)



（d）Soil (other earthquakes)



（e）Soft soil (Chi-chi earthquakes)



（f）Soft soil (other earthquakes)

Figure 1 PGA versus Rp or Rr curves (continued)

different. Also, from these figures, comparison and analysis work can be easily done. In fact, these attenuation relationships have their own application scope because they were regressed with earthquake records in different fault distance, such as X.L. Li. adopted records within Rp≤15km, G.B. Shao within Rp≤25km. It is found that when this scope is extended to Rp or Rr≤30km, they also can reflect the attenuation regulations of PGA.

Figure (a) and (b) shows that for firm soil, results from Huang agree well with recorded PGA except for Rp<2km, results from Ambraseys is a little smaller and Li-2 is bigger than those recorded ones, results from others are close to each other but a bit higher than recorded ones. This mainly because different records, site category and attenuation relationship models were adopted during the process of regression, such as only reverse records within Rp<15km were used to get Li-2 attenuation relationship. From figure (c) and (d), it can be seen that for soil, results from Ambraseys agree well with recorded PGA for Chi-chi earthquake but relatively lower for other earthquakes. Results from Li-1 and Li-2 are relatively higher, yet results from Shao and Compbell agree relatively well with the recorded ones for other earthquakes but a bit bigger for Chi-chi earthquake. Figure （e） shows results from Ambraseys agree well with recorded PGA in Chi-chi earthquake, yet results from others are a bit higher than recorded ones but are close to each other. For there are not records with Rr and Rp for soft soil in the database of PEER, so figure (f) shows PGA changes with Rr. From it, it can be seen results from C.H.Yeh is larger than real recorded PGA for Rp<12km but larger for the rest.

In all, although different factors and expression forms are used in the attenuation relationships, except for results from Ambraseys are relatively smaller and results from Li-2 are lager than the others, the difference between the other attenuation relationships is small. In fact, results from each attenuation relationship agree well with the recorded PGA used to get it. So a good PGA attenuation relationship which can well reflect the statistic attenuation law should be approximate to both the real recorded PGA and most of the other ones，also it should be simply expressed so as to be used conveniently. Among these attenuation relationships, almost all influencing factors are considered in Compbell, including magnitude, fault type, hanging wall effect, soil category and fault distance. Also, results from it agree well with most of the others, so it's recommended to be used in research. Results from Shao relatively agree well with the former mentioned rules, though it's a bit higher for soft soil and doesn't including fault type influencing factors. But for reverse fault earthquake, Li-2 is safer than the others.

5. COMPARISON AND ANALYSIS OF ATTENUATION RELATIONSHIPS OF PGV

5.1. Attenuation Relationships of PGV

During the process of studying PGA, PGV was also selected as a new parameter to describe earthquake ground motions, because it was believed that PGV was relevant to earthquake energy. So some near-fault attenuation relationships of PGV appeared and some representative ones are listed in table 2.

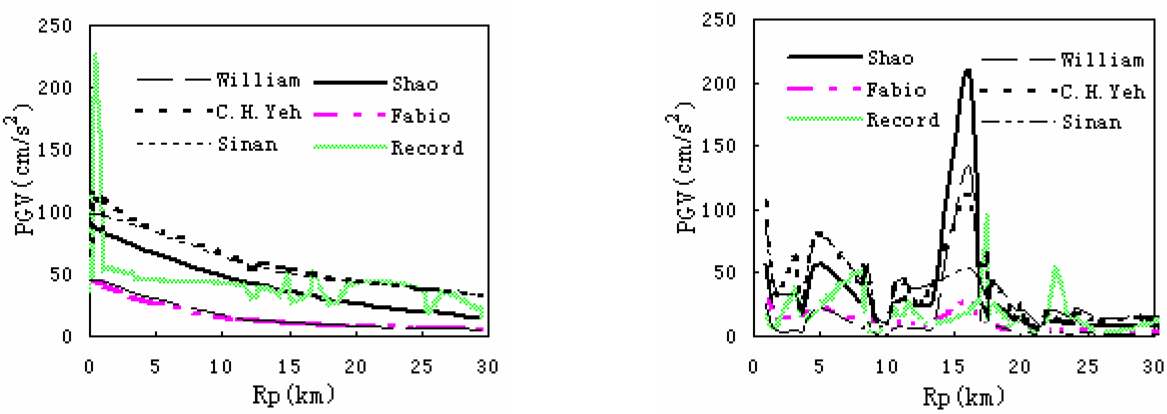
Table 2 Attenuation relationships of PGV

Attenuation relationships of PGV	Name
$\log PGV = -0.67 + 0.489Mw - 0.5\log(d^2 + 4.0^2) - 0.00256Rr + 0.17Ss + 0.22P$	William
$\log PGV = -0.710 + 0.455Mw - 0.5\log(Rp^2 + 3.6^2) + 0.133Ss$	Fabio
$\log_{10} PGV = -2.22 + 0.69M_W - 0.581\log_{10} Rp$	Somerville
$\log PGV = \begin{cases} -1.267\log(Rr + 0.0022e^{1.189Mw}) - 0.0023Rr + 1.507Mw & \text{(Taiwan)} \\ -1.454\log(Rr + 1.4) - 0.0023Rr + 1.769Mw - 3.424 & \text{(China)} \end{cases}$	C. H. Yeh
$\log_{10} PGV = -1.36 + 1.063M_W - 0.079Mw^2 + (-2.948 + 0.306Mw)\log\sqrt{Rp^2 + 5.547^2} + 0.243Ss + 0.087Sa - 0.057F_N + 0.0245F_R$	Sinan
$\log PGV = \begin{cases} -0.6615 + 0.3463Mw - 0.0262Rp - 0.0021d & \text{firm soil} \\ -1.1646 + 0.4299Mw - 0.0159Rp - 0.0030d & \text{soft soil} \\ -0.7649 + 0.3729Mw - 0.0229Rp - 0.0044d & \text{soil} \end{cases}$	Shao

The parameters in the original attenuation relationship were all also changed to the same signals: horizontal peak ground velocity (PGV); influencing factors of fault type (F_N and F_R), for normal fault, F_N=1, for reverse fault, F_R=1; P is zero for 50 percentile values and one for 84 percentile values. Other signals have the same physical meaning as PGA.

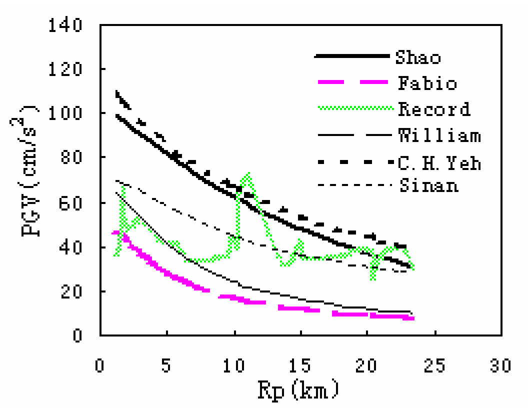
5.2. Comparison and Analysis of the Calculated Results and Recorded PGV

Figure (a)-(f) shows PGV versus Rp or Rr. All the abscissa represents Rp except figure (f) for the records limitation. All curves in figure (a), (c) and (e) are gotten based on Chi-chi earthquake records, which revealed

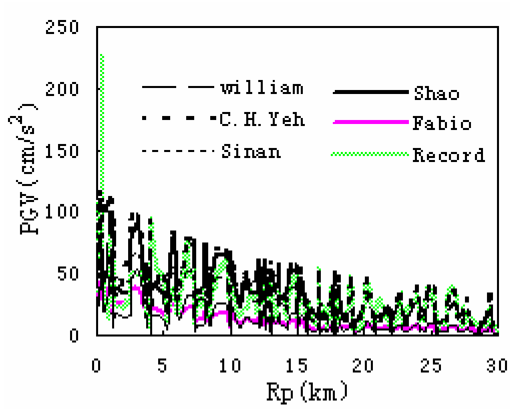


(a) Firm soil (Chi-chi earthquakes) (b) Firm soil (other earthquakes)

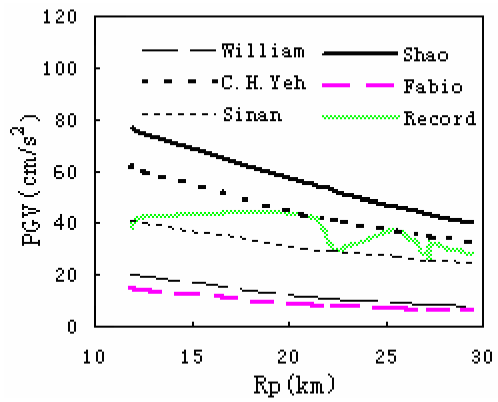
Figure 2 PGV versus Rp or Rr curves



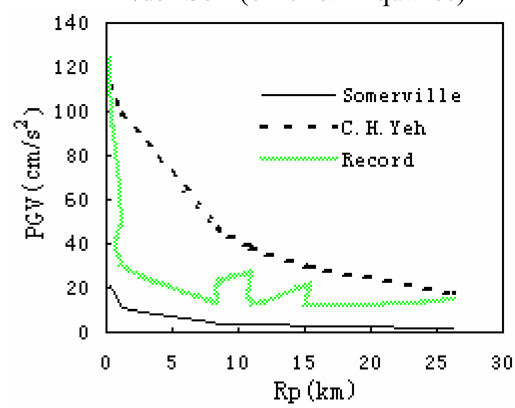
（c） Soil (Chi-chi earthquakes)



（d） Soil (other earthquakes)



（e） Soft soil (Chi-chi earthquakes)



（f） Soft soil (other earthquakes)

Figure 2 PGV versus Rp or Rr curves (continued)

how PGV changes with Rp when magnitude is the same. Curves in the rest figures are gotten based on the other earthquakes around the world, which reveals how PGV changes with Rp or Rr when magnitudes are different. Also, when the application scope of these attenuation relationships is extended to Rp or Rr≤30km, they still can reflect the attenuation regulations of PGV.

It can be seen from figure 2: for firm soil and soil, results from Shao agree well with recorded PGV, yet those from C.H.Yeh and Sinan are a bit larger; those from William and Fabio are smaller; for soft soil, results from Shao are a little larger than recorded ones, those from William and Fabio are smaller, yet those from C.H.Yeh agree well with recorded PGV. But in all, results from Shao are relatively reasonable. The reasons for this difference among these PGV attenuation relationships are the same as PGA.

6. CONCLUSIONS AND FORESIGHT

From the above comparison and analysis, the following conclusions can be gotten:
(1) When the scope of the attenuation relationship was extended to Rp or Rr≤30km, they also could reflect near-fault horizontal attenuation regulations of PGA or PGV;
(2) As far as attenuation relationships of PGA are concerned, Shao is perhaps a better choice except reverse-fault earthquake. For reverse-fault earthquake, Li-2 is safer than the others. In research work, Compbell is recommended for it's considering almost all influencing factors;
(3) Results of PGV from Shao are reasonable for firm soil and soil, but for soft soil, it is a bit larger than recorded ones, yet results from C.H.Yeh agree well with recorded PGV. In all, Shao is recommended.
Certainly, although some kinds of attenuation relationship of PGA and PGV are recommended, it's should be known that there are still some shortcomings in them, such as influencing factors of fault types doesn't included

in Shao and results from it are a bit larger for soft soil, results from Li-2 are larger than recorded ones, it's too complicated to use Compbell attenuation relationship. All these problems should be done in the future.

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