Attenuation Function of Ground Motions for Guangdong Region of Southern China

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ATTENUATION FUNCTION OF GROUND MOTIONS FOR
GUANGDONG REGION OF SOUTHERN CHINA

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ABSTRACT

We made use of the first ever set of horizontal-component digital seismic data of 44 earthquake
events (ML = 2.5 to 5.1) from September 1999 to October 2000, recorded by 14 stations of the
Guangdong Telemetered Network to determine the attenuation function of S-wave phases of ground
motions for the Guangdong Region of southern China.

It was found that the geometrical spreading function of the region could be best represented by a tri-
linear piecewise continuous function. At a distance less than 45 km from a seismic source, the
geometrical spreading coefficient was 0.97. Between 45 and 100 km, the coefficient was nearly zero.
Beyond 100 km, the coefficient was 0.5. The frequency-dependent Q was estimated to be Q =
481.5f⁻⁰.³¹

We then evaluated the source spectra for each of the 44 events from the records of the YHK Station of
the Hong Kong Observatory’s seismic monitoring network, and the proposed attenuation model. It
was found that the so-obtained source spectra derived from YHK Station were comparable to those
derived from the stations of Guangdong Network. Hence, the proposed attenuation function was
likely to be applicable for the Hong Kong region as well.

INTRODUCTION

In seismology, the analysis of attenuation characteristic of ground motions provides a better
understanding on wave transmission inside the earth, and the seismic source parameters. In
engineering applications, the attenuation relationships of S-wave phases of ground motions are of
most interest as their amplitudes are approximately five times larger than the associated P-wave
phases, causing most of the earthquake damages. Therefore, a quantification of the S-wave
attenuation is necessary for seismic hazard analysis of a region.

Traditionally, researchers tended to study the attenuation and hazard issues for seismically active
regions. After the Newcastle Earthquake in 1989 which occurred in a region of low seismicity and
cau sed significant damages valued at about 700 million Australian dollars (Brunsdon, 1990),
earthquake hazard analysis of a region of low seismic risk but high consequence of economic losses
has received more attention. In recent years, as there has been a tremendous economic growth in
Guangdong, a province of low to moderate seismicity, the need to proper assess the attenuation of
ground motions and seismic risk of this region is apparent.
It has been recognized that the attenuation of wave transmission in a region can be reliably estimated from calculations based on extensive ground motion data recorded in the region. As the quantity of useable strong ground motion data in China is small, even for high seismic regions, the attenuation characteristics have been formulated using the intensity records in China. However, there is a concern on the accuracy of such approach.

In 1999, the Guangdong Digital Seismograph Network was established in the Guangdong Province of China, and recording of digital ground motion data from 14 telemetered stations of the Network commenced in August of the same year. In collaboration with Guangdong Seismological Bureau, the first ever-complete set of digital ground motion data of the region was used to evaluate S-wave attenuation. Results of the study, including the geometrical spreading coefficients, the anelastic attenuation and site responses of the Guangdong region, and the applicability of the proposed attenuation function for the Hong Kong region are reported in this paper.

SEISMOGRAM DATA

The dataset consists of 249 selected horizontal-component digital seismograms from 44 earthquake events (M_L = 2.5 to 5.1) between September 1999 to October 2000, recorded by the Guangdong Telemetered Network. Figure 1 shows the locations of the stations and the events. The distances between the earthquake hypocenters and the observation stations vary from 10 km to 500 km.

![Figure 1. Distribution of stations and seismic events (open triangles indicate location of stations and solid circles indicate locations of seismic events)](image)

FOURIER SPECTRUM OF GROUND MOTION

The observed shear wave spectral amplitude of event \(i\) at station \(j\) can be written as follows

\[
A_y(f) = A_{i0}(f) \cdot G(R_y) \cdot S_j(f) \cdot e^{-\frac{\pi f R_y}{Q(f) \beta}}
\]  

where \(A_{i0}\) is the source term of event \(i\), \(G\) is geometric attenuation function, \(R_y\) is hypocentral distance, \(S_j\) is site response, and \(Q\) is frequency-dependent, and \(\beta\) is shear wave velocity.

Taking logarithm on two sides; we get the following equation.

\[
\log A_y(f) = \log A_{i0}(f) + \log G(R_y) - c(f) \cdot R_y + \log S_j(f)
\]
where \( c(f) \) is the coefficient of anelastic attenuation, which is

\[
c(f) = \frac{\log(e) \cdot \pi \cdot f}{Q(f) \cdot \beta}
\]  

(3)

**GEOMETRICAL SPREADING FUNCTION \( G(R) \)**

For the geometrical attenuation function, early studies suggested that at near source distances, the geometric spreading coefficient was 1, and at regional distances where the dominant phase was \( Lg \) wave, the geometric spreading coefficient was 0.5. However, recent studies (Burger et al., 1987, Ou and Herrmann, 1990) indicated that the shape of geometric attenuation function was complex even for a simple layered crustal model. Within a medium source distance, the amplitudes might increase or remain constant. In this study, we tried linear, bilinear and trilinear piecewise continuous functions to fit the ground motion data, and found that the trilinear model (Equation 4) yielded the best results or the least residual error (as defined below). Here we just outlined the procedure for determining the geometrical spreading coefficients of the trilinear model which was based on the method proposed by Atkinson and Mereu (1992).

\[
G(R) = \begin{cases} 
R^{-b_1} & R \leq R_1 \\
R_1^{-b_1} \cdot R^{b_2} \cdot R^{-b_2} & R_1 < R \leq R_2 \\
R_1^{-b_1} \cdot R_2^{b_2} \cdot R^{b_2} \cdot R^{-b_2} & R_2 < R
\end{cases}
\]  

(4)

where \( b_1, b_2 \) and \( b_3 \) are geometric spreading coefficients for their respective hypodistance ranges.

**Iteration Inversion Process**

Combining Equations 2 and 4, the source term for event \( i \) observed at station \( j \), \([\log A_{io}(f)]_j\) for respective hypodistances can be written as follows:

\[
[\log A_{io}(f)]_j = \log A_j(f) + b_1(f) \log R_j + c(f)R_j - \log S_j(f)
\]  

\( R \leq R_1 \)

\[
[\log A_{io}(f)]_j = \log A_j(f) + b_1(f) \log R_1 + b_2(f) \log(R_j / R_1)
\]  

\( + c(f)R_j - \log S_j(f) \)

\( R_1 < R \leq R_2 \)

\[
[\log A_{io}(f)]_j = \log A_j(f) + b_1(f) \log R_1 + b_2(f) \log(R_j / R_1)
\]  

\( + b_3(f) \log(R_j / R_2) + c(f)R_j - \log S_j(f) \)

\( R_2 < R \)

We then defined the residual error \( Res \) as:

\[
Res = \sum_{i}^{n} \sum_{j}^{n} |K_{ij}(f)|
\]  

(6)

where

\[
K_{ij}(f) = [\log A_{io}(f)]_j - \log A_{io}(f)
\]  

(7)
and $\overline{\log A_0(f)}$ is the mean source amplitude for event $i$, which is defined:

$$\log A_0(f) = \frac{\sum_{j=1}^{n_i} [\log A_0(f)]_j}{n_i}$$

(8)

where $n_i$ is the number of stations recording the event $i$, $n_0$ is the total number of events used in the analysis.

The residual $Res$ is a function of $(b_1, b_2, b_3$ and $c)$, the frequency $f$, and sources distances $(R_1, R_2)$. In order to reduce the number of unknowns in the inversion process, we took $b_3$ equal to 0.5, judging from the previous studies on $Lg$ waves.

For a specific frequency $f$, the site response of all stations was initially taken to be zero, and some trial values of $R_1$ and $R_2$ were selected. We used Genetic Algorithm (GA) to search for the combination of attenuation parameters $(b_1, b_2, c)$ that gave minimum residual error. The increment of the site response correction $\Delta \log S_j(f)$ for station $j$ was calculated from Equation 9.

$$\Delta \log S_j(f) = \frac{\sum_{m_j} K_{ij}(f)}{m_j}$$

(9)

where $m_j$ is event numbers recorded at station $j$.

The above-mentioned process was repeated, using these new site terms. Iteration continued until no further reduction in the residual error was possible. We then changed the values of $R_1$ and $R_2$, and repeated the whole process again and again till a pair of $(R_1$ and $R_2)$ yielded the least residual error, so that the best set of attenuation parameters and site response were finally obtained.

**Coefficients of Geometrical Spreading Function**

Based on the aforesaid process, we derived the best pair of $R_1 = 45km$ and $R_2 = 100km$. The associated geometrical attenuation coefficients $b_1, b_2$ and site terms $S_j(f)$ for each sampling frequency were also determined. By definition, the geometric attenuation coefficients $b_1$ and $b_2$ should be independent of frequency. However, as the inversion process was conducted for each sampling frequency, we obtained one set of $(b_1, b_2, c)$ for each sampling frequency. Figure 2 shows the values of $b_1$ and $b_2$. We took the average value of each parameter, and obtained: $b_1 = 0.97 \pm 0.11$, $b_2 = 0.0097 \pm 0.15$, and $b_3 = 0.5$ as our final solutions.

In order to study the attenuation due to the path effects only, we defined the so-called normalized amplitude $\log A'_0(f)$ (Equation 10), by subtracting the source term and the site term of Equation 2.

$$\log A'_0(f) = \log A_0(f) - \log A_0(f) - \log S_j(f)$$

(10)

Figure 3 compares the observed decay of normalized amplitude with that obtained from the proposed attenuation function for $f = 8.91$ Hz, as a typical example. It is evident that there is a significant flattening in the decay of spectral amplitudes in the transition zone of the source distances ranging from 45 km to 100 km.
Figure 2. Values of $b_1$ and $b_2$ vs frequency $f$ (thick line indicates average value).

Figure 3. Observed decay of normalized amplitude (for $f = 8.91$ Hz).

ANELASTIC ATTENUATION

Figure 4 plots the coefficients of anelastic attenuation, $e(f)$, as well as $Q(f)$. For the frequency below 2 Hz, the calculated $Q$ values are quite scattered. Therefore, we only regressed the results above 2 Hz, and obtained the frequency-dependent $Q$ as $Q = 481.5 \cdot f^{-0.31}$. 
Figure 4 Coefficient of anelastic attenuation $c$ and $Q$ vs frequency
(straight line is $Q = 481.5 \cdot f^{0.31}$)

Figure 5 compares our $Q$ model for S waves in the Guangdong region with the $Q$ models for S or Lg waves in other regions [Mark “1” $Q = 130f^{0.10}$ for Apennines of Italy (Malagnini et al., 2000a); Mark “2” $Q = 150f^{0.5}$ for West America (Chin and Aki, 1991); Mark “3” $Q = 56f^{0.01}$ for Oaxaca of Mexico (Castro and Munguia, 1993); Mark “4” $Q = 400f^{0.42}$ for Central Europe (Malagnini et al., 2000b); Mark “5” $Q = 670f^{0.33}$ for Eastern Canada (Atkinson and Mereu, 1992); Mark “6” $Q = 508f^{0.48}$ for Indian shield region (Singh et al., 1999); and Mark “7” $Q = 680f^{0.36}$ for Eastern North America (Atkinson and Boore, 1995)]. We found that the $Q$ model for shear waves in the Guangdong region is similar to that in Central Europe.

Figure 5. Comparison of $Q$ models of $S$ waves of different regions (P - Guangdong region, 1 - Apennines, 2 - West America, 3 - Oaxaca of Mexico, 4 - Central Europe, 5 - Eastern Canada, 6 - Indian shield region, 7 – Eastern North America)
CORRELATION WITH GROUND MOTION DATA RECORDED BY THE HONG KONG OBSERVATORY

For geological considerations, Hong Kong is part of the Guangdong region. In the derivation of the above-mentioned model and parameters, we have not used the ground motion data recorded in Hong Kong. In fact, the Hong Kong Observatory operates a network of eight stations to record ground motions in digital format since 1997.

In this section, we tried to establish the source spectra of the same 44 events from the digital signals recorded by YHK station of the Hong Kong Network, assuming that there was no site amplification effect of YHK station as it was sited on hard bedrock, and using our proposed geometric spreading function and Q function derived from the Guangdong Digital Seismograph Network data.

It was found that source spectra of the selected events derived from the 14 Guangdong stations and from YHK station were comparable, and the discrepancies were well within an acceptable range. Figure 6 is an example of comparison of the source spectra of the Heyuan Earthquake (M_s = 3.1, occurred on 4 November 1999) calculated from 5 Guangdong stations and the YHK station. The thick line is derived form YHK station. It also confirms insignificant site amplification effect at YHK station.

Figure 6  Comparison of source displacement spectra recorded at different stations for Heyuan Earthquake of 4 November 1999 (M_s = 3.1) (thick line is from records of YHK Station after corrected for attenuation)

SUMMARY OF FINDINGS

Based on the 249 Fourier spectra of 44 earthquake events recorded by the 14 stations of the Guangdong Telemetered Network, the attenuation model and source parameters were estimated using the Genetic Algorithms inversion.

The results can be summarized as following:

* The geometrical spreading function shows three distinct sections for the Guangdong region. At a source distance less than 45 km, corresponding to geometrical spreading of the direct wave, the geometrical spreading coefficient is 0.97. At a source distance between 45 and 100 km, the
geometrical coefficient is nearly zero. At a source distance beyond 100 km, corresponding to
the Lg phase, the geometrical spreading coefficient is 0.5.

* The frequency-dependent $Q$ is estimated as $Q = 481.5 \cdot f^{0.31}$.

* Preliminary study of the digital seismograph data of the same 44 events recorded by Hong Kong
Observatory seismic monitoring network indicates that the proposed attenuation model is likely
to be applicable for Hong Kong Region.

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