Estimation of κ Factor for Two Types of Sites in Northeast India

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ABSTRACT

The near surface high frequency attenuation parameter kappa (κ) is estimated from the strong ground motion records of earthquakes at multiple epicentral distances from two nearby stations, one on firm ground and other on soft rock in the Shillong array of Northeast India. A total of 22 horizontal components of accelerograms have been used to estimate κ. The records were obtained from seven earthquakes with magnitudes ranging from 5.2 to 7.2. The Anderson and Hough (1984) model is used to compute and study the κ, which for horizontal component of ground acceleration is obtained as 0.0637 sec for firm ground type of site and 0.0756 sec for soft rock type of site. It is found that κ is almost constant with respect to distance and is a characteristic parameter for local site soil condition only.

1. INTRODUCTION

The Northeast Indian region is seismically most active region with many active seismo-tectonic formations like eastern Himalayas, Naga-Disang Thrusts, Shillong Plateau, etc. (Kayal et al., 2006). Two devastating earthquakes of magnitudes more than 8 on Richter scale have occurred in 1897 and 1950 in this area. Any major earthquake in future will cause immense loss of human lives and property. To mitigate this loss, the seismic hazard estimation of the region and thereafter its application in the design and construction of important buildings and structures of engineering importance is very much essential. The ground acceleration beneath a structure is the main cause of collapse of any building during earthquakes. The peak ground acceleration and response spectra at a site are two important design seismic parameters for earthquake resistant design of structures. The frequency and amplitude of seismic waves generated at the hypocenter of an earthquake gets modified during propagation from source to the recording station. A ground motion simulation model is therefore required to consider all the source path and site effects in a realistic way. The near site high frequency attenuation parameter kappa (κ) is an important controlling factor in the high frequency range for the simulation of ground motion. As this is a site-specific property, this has to be estimated using the available strong motion data in a region (Akinci, 2001; Atkinson, 1996; Bersenev, 2002; Chapman, 2003). In the present study, the site-specific nature of kappa has been investigated and illustrated by estimating its values for two nearby strong-motion recording sites in the Shillong array. The site condition beneath one site (Umrongso) is soft rock whereas beneath the other one as firm ground (Ummulong). Both the sites have recorded several accelerograms from seven different earthquakes with widely differing magnitudes and distances. The distance between these two stations is very small as compared to the epicentral distances of earthquakes recorded at these stations. This choice eliminates the effect of path and hence the values estimated for two types of geological conditions can be compared on the basis of site geology alone.

2. STRONG MOTION DATA

The Earthquake Engineering Department of Indian Institute of Technology at Roorkee is operating a strong motion array in Shillong area of Northeast India (Chandrasekaran and Das, 1992). The strong motion acceleration data recorded at two stations of the Shillong array has been used in this study. These stations are Umrongso(25.52 °N, 92.63 °E) and Ummulong (25.52 °N, 92.17 °E). The Umrongso station is located on firm ground and Ummulong on soft rock. The database consists of 22 horizontal components of acceleration records generated due to seven earthquakes during 1986 to 1999. Twelve records are obtained on firm ground and ten on soft rock. SMA at Umrongso station recorded acceleration due to six events and at Ummulong station from five events. Four common events generated records at both the stations. Figure-1 shows the locations
of the two stations and major tectonic features in the region. The epicentral distances from the stations vary from 8 km to 325 km. The date of occurrence, epicentral location, focal depth and magnitude of the seven contributing events are given in Table-1. First four events listed in the table occurred in the Indo-Burma region. These are related to subduction tectonics. Remaining three events are of crustal nature.

Fig. 1: Map Showing the Locations of Two Stations Along with Major Tectonic Features in the Region.

Table 1: Details of the Contributing Earthquakes

<table>
<thead>
<tr>
<th>EQ #</th>
<th>Date</th>
<th>Lat.</th>
<th>Long.</th>
<th>Depth</th>
<th>Mag.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>dd/mm/yyyy</td>
<td>°N</td>
<td>°E</td>
<td>(km)</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>18/05/1987</td>
<td>25.48</td>
<td>93.60</td>
<td>50</td>
<td>6.2</td>
</tr>
<tr>
<td>2</td>
<td>06/08/1988</td>
<td>25.19</td>
<td>94.89</td>
<td>91</td>
<td>7.2</td>
</tr>
<tr>
<td>3</td>
<td>10/01/1990</td>
<td>24.74</td>
<td>95.26</td>
<td>118</td>
<td>6.3</td>
</tr>
<tr>
<td>4</td>
<td>06/05/1995</td>
<td>24.99</td>
<td>95.29</td>
<td>117</td>
<td>6.4</td>
</tr>
<tr>
<td>5</td>
<td>10/09/1986</td>
<td>25.56</td>
<td>92.20</td>
<td>28</td>
<td>5.2</td>
</tr>
<tr>
<td>6</td>
<td>06/02/1988</td>
<td>25.50</td>
<td>91.46</td>
<td>15</td>
<td>5.8</td>
</tr>
<tr>
<td>7</td>
<td>08/15/1997</td>
<td>24.51</td>
<td>92.36</td>
<td>35</td>
<td>5.9</td>
</tr>
</tbody>
</table>

The original accelerograms were recorded on 70 mm photographic film. These were digitized at Department of Earthquake Engineering, IIT, Roorkee. The digitized acceleration records scaled to the units of time and acceleration were processed for the correction of high frequency digitization noise, dynamic response of the recording transducers and the base line distortions (Trifunac 1971; Trifunac 1972; Gupta 2010). The upper cut-off frequency for all the corrected accelerograms is 25 Hz and the lower cut-off frequency ranges between 0.3 and 0.7 Hz. Such processed records have been used to derive the site parameter kappa for the two sites.

3. METHOD

For a point source seismological model, the Fourier amplitude spectrum of ground acceleration \( Y(f, r) \) at a site can be expressed as (Boore 1983, 2003)

\[
Y(f, r) = C \cdot S(f) \cdot D(f, r) \cdot F(f)
\]

Here \( C \) is a constant, \( S(f) \) is source spectrum, \( D(f, r) \) accounts for path effect, \( r \) is the epicentral distance and \( f \) is frequency. \( F(f) \) is a composite function and characterizes the site effects on the spectrum.

\[
F(f) = A(f) \cdot P(f)
\]

Here \( A(f) \) represents the site amplification and \( P(f) \) is path independent attenuation function defined as

\[
P(f) = e^{-\kappa f}
\]

with \( \kappa \) as the site parameter. This accounts for attenuation of high frequency amplitudes above some threshold frequency and characterizes the near surface attenuation (Anderson, 1984). Using this relationship, the high-frequency Fourier amplitude spectrum at a site can be approximated as

\[
AFS(f) = e^{-\kappa f}
\]

Taking logarithm of both the sides, it can be written as

\[
\ln AFS(f) = \ln A_0 - \kappa f
\]

This is the equation of a straight line with slope \(-\kappa\). To estimate \( \kappa \), the Fourier spectra of acceleration data were computed using the Fast Fourier Transform (FFT) routine. The log of spectral amplitude versus frequency was then plotted for the frequency range 0 to 25 Hz. It was observed that in almost all cases, the log of spectral amplitude decreased linearly with frequency beyond 10 Hz. To obtain spectral decay parameter \( \kappa \), the spectrum of each record was fitted with a straight line using least square approach over the chosen frequency band. The frequency band was chosen visually for each spectrum. It is above corner frequency and below a frequency at which the spectrum is dominated by noise. Figure - 2 shows a typical example of the Fourier spectra with best-fit straight lines to estimate \( \kappa \).
4. RESULTS AND DISCUSSION

Strong motion data consisting of 22 horizontal components of acceleration records from seven earthquakes in the Northeast Indian region has been used for calculating the parameter \( \kappa \). This factor characterizes the near surface high frequency attenuation. The two stations located in the same tectonic domain have been chosen to represent two types of site conditions. Six events have been recorded at one station and five events at other stations. Kappa has been estimated for a site on soft rock and another on firm ground. The average value of \( \kappa \) is 0.0637 sec for firm ground and 0.0756 sec for soft rock site. These values compare well with the values estimated by different investigators for various part of the world (Table-2). The estimated kappa factors for both firm ground and soft rock sites are plotted with respect to epicentral distance in Figure-3(a) and 3(b), respectively. The slope of the least squares lines fitted to these data is not found to be significantly different from zero. This justifies the notion that kappa is basically a distance independent parameter (Atkinson and Silva, 1997; Atkinson, 1996). It is a characteristic parameter of the geological conditions below and near the site.

**Table 2:** Kappa Values for Different Parts of the World

<table>
<thead>
<tr>
<th>Region</th>
<th>Reference</th>
<th>( \kappa )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Memphis</td>
<td>Hermann and Akinci(1999)</td>
<td>0.063</td>
</tr>
<tr>
<td>St Louis</td>
<td>Hermann and Akinci(1999)</td>
<td>0.007</td>
</tr>
<tr>
<td>Greece</td>
<td>Basil et al (1998)</td>
<td>0.060</td>
</tr>
<tr>
<td>Central Europe</td>
<td>Maligini (2000)</td>
<td>0.050</td>
</tr>
<tr>
<td>WNA</td>
<td>Besenev (2002)</td>
<td>0.050</td>
</tr>
<tr>
<td>Iran</td>
<td>Motezedian (2006)</td>
<td>0.050</td>
</tr>
</tbody>
</table>

To investigate the dependence of \( \kappa \) on magnitude \( M \) of the events, plots of \( \kappa \) versus \( M \) are shown in 4(a) and 4(b). The slopes of the least square lines are 0.002 and 0.0005 for two types of site conditions, indicating very insignificant dependence on magnitude. To estimate source contribution to the kappa, dependence on magnitude has been also studied for various parts of the world (Atkinson and Silva, 1997; Parolai et al., 2007; Akinci, 2001). The present findings are similar to those of the previous studies.

5. CONCLUSIONS

The use of \( \kappa \) factor provides the simplest way to model the effects of local site condition in ground motion simulation. The present paper has obtained the \( \kappa \) values for two nearby sites, viz. Umrongso and Ummulong, in the Shillong array of strong-motion accelerographs. The average \( \kappa \) values for these sites, which are characterized by soft rock and firm soil type of geology, are found to be 0.0637 and 0.0756, respectively. Also, these values are seen to be associated with quite large dispersion. Therefore, a more stable estimate of \( \kappa \) for an area may be provided by the average value for all the recording stations characterized by same type of geology. Nevertheless, the present paper provides a good illustration on the site-specific nature of the \( \kappa \) value.

**REFERENCES**

Malagnini L. Hermann, R.B. Ground motion scaling in the region of 1997 Umbria Marche earthquake Italy *Bull. Seismo. Soc. Am.* 90, 0, 1041-1051