Seismology based strong ground motion attenuation relationship for national zoning map

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Background

- Empirical method
- For regions with enough data (e.g. western US and Japan)
- For most countries or regions?
- More and more strong motion observation instruments are installed...
  - Space
  - Time

How to establish relationships for regions with few or without strong ground motion records?

National strong motion observation network system (Li et al., 2008)

In China, strong ground motion records are not enough now.

Mapping method (Hu, 1980s):
This method assumes that, for region A of enough acceleration observation data and a region B of few such data, earthquake pairs \((M_A, R_A; M_B, R_B)\) exist in the intensity attenuation curves \(I(T_A, M_A, R_A)\) of region A and \(I(T_B, M_B, R_B)\) of region B, so that they give the same intensity \(I\) and ground motion \(Y\).

Region A:

\[
I = 0.514 + 1.556M - 0.00665\log Y = 2.014 \log (Y + 10)
\]

\[
\log (I) = 1.297 + 0.566 \log Y = 1.723 \log (Y + 1.066^{1.56})
\]

Region B:

\[
I = 5.019 + 1.146M - 4.136 \log (Y + 24)
\]

\[
\log (I) = 2.027 + 0.548 \log Y = 1.902 \log (Y + 1.700^{3.28})
\]
Framework

- Target region
- Data from digital seismic network
- Strong ground motion attenuation relationship
- Data from strong motion network
- Empirical relations

Methodology

Assuming the accelerations, on the far-field and an elastic half space, are band-limited, finite-duration, white Gaussian noise, and based on Brune’s model, the source Fourier spectra \( F_A(M_0, f, R) \) on a site can be described as

\[
F_A(M_0, f, R) = C \cdot S(M_0, f) \cdot G(R) \cdot D(R, f) \cdot A(f) \cdot P(f) \cdot I(f)
\]

where, \( C \) is proportion factor; \( S(M_0, f) \) is source spectrum for a specified seismic moment; \( G(R) \) is geometric spreading function; \( D(R, f) \) is anelastic attenuation function; \( A(f) \) is the amplification factor of near surface amplitude; \( P(f) \) is a high-cut filter that rapidly reduces amplitudes at high frequencies; \( I(f) \) is spectrum shape parameter, used to shape the spectrum to correspond to the particular ground-motion measure of interest.

\[
C = \frac{R_o \cdot F_V \cdot \alpha \cdot \gamma}{4 \pi R_o \cdot \alpha \cdot \gamma}
\]

\[
S(M_0, f) = \frac{M_0}{1 + \left( \frac{f}{f_c} \right)^2}
\]

\[
f_c = 4 \times 10^7 \times (\Delta \sigma_0 / M_0)^{1/3}
\]

\[
G(R) = \begin{cases} \frac{1}{R} & 0 < R < 70 \\ \frac{1}{\sqrt{R}} & 70 < R < 130 \\ \frac{1.2}{\sqrt{R}} & R \geq 130 
\end{cases}
\]

According to the relation between Fourier spectrum and power spectrum, the latter can be calculated by the following numerical integration,

\[
\omega_m = 2 \int_{T_d/2}^{T_d} \omega \cdot |S(f)|^2 df
\]

The peak factor \( \gamma_m \), which describes the ratio of peak to rms motion, is calculated by the following numerical integration,

\[
\gamma_m = 2 \int \left| 1 - \frac{\omega}{\omega_m} \exp \left[ -\frac{\omega^2}{\omega_m^2} \right] \right| df
\]

\[
z = \frac{N_c}{N} \cdot \frac{m_i}{m_{ss}} \cdot f_c \cdot T
\]

\[
N_c = 2f_c \cdot T
\]

\[
\omega_m = \frac{1}{2 \pi} \left( \frac{m_i}{m_s} \right) f_c
\]

\[
\omega_m = \frac{1}{2 \pi} \left( \frac{m_i}{m_s} \right) f_c
\]

PGA = \( v_m \cdot \omega_{ms} \)

CASE OF SENDAI AREA
13 1996.1-2011.4
12 F-net stations
632 earthquakes

Distribution of hypocentral distance with Mw

Distribution of focal depth with Mw

Inversion ranges

<table>
<thead>
<tr>
<th>Δσ</th>
<th>Qo</th>
<th>η</th>
</tr>
</thead>
<tbody>
<tr>
<td>40~100 bars</td>
<td>100~300</td>
<td>0.6~1</td>
</tr>
</tbody>
</table>

Inversion results

<table>
<thead>
<tr>
<th>Δσ</th>
<th>Qo</th>
<th>η</th>
</tr>
</thead>
<tbody>
<tr>
<td>45.17 bars</td>
<td>124.91</td>
<td>0.61</td>
</tr>
</tbody>
</table>

PGA attenuation relations

Strong motion data from K-NET
- 4256 strong motion data (Mw≥4.5 and focal depth≤30 km)
- 88 K-NET bedrock stations (T₀<0.2s)
Empirical relations

  \[ \log(\text{PGA}) = 0.56 M_w - 0.0033 X - \log(X + 0.005510^{0.5X}) + 0.26 + 0.37 \]
  \[ \log(\text{PGA}) = 0.58 M_w + 0.0039 D + 0.12 + 0.28 - \log X_{eq} - 0.0033 X_{eq} \]
  \[ \log(\text{PGA}) = 0.41 M_w - \log(\pi (R + 0.032 \cdot 10^{0.4 M_w}) - 0.0034 R + 1.30 \]

\[ \text{residual} = \frac{1}{N} \sum_{i=1}^{N} \frac{\text{observed value}}{\text{predicted value}} \]

<table>
<thead>
<tr>
<th>PGA relations</th>
<th>Mw=5</th>
<th>Mw=6</th>
<th>Mw=7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fukushima (1990)</td>
<td>-0.2970</td>
<td>-0.0613</td>
<td>0.0887</td>
</tr>
<tr>
<td>Kanno (2006)</td>
<td>-0.4168</td>
<td>-0.3503</td>
<td>-0.3591</td>
</tr>
<tr>
<td>Si (2000), D=10</td>
<td>-0.2003</td>
<td>-0.1698</td>
<td>-0.2407</td>
</tr>
<tr>
<td>Si (2000), D=20</td>
<td>-0.2393</td>
<td>-0.2088</td>
<td>-0.2797</td>
</tr>
<tr>
<td>Si (2000), D=30</td>
<td>-0.2783</td>
<td>-0.2478</td>
<td>-0.3187</td>
</tr>
<tr>
<td>This study</td>
<td>-0.5093</td>
<td>-0.3894</td>
<td>-0.2520</td>
</tr>
</tbody>
</table>

Case of Southwestern China

Sichuan Province
2001-2007
29 seismic stations
48 earthquakes
147 records

Yunan Province
2001-2007
26 seismic stations
162 earthquakes
863 records

Distribution of hypocentral distance with Mw
Inversion ranges (Ye, 2001; Su, 2009)

<table>
<thead>
<tr>
<th>$\Delta \sigma$</th>
<th>$Q_o$</th>
<th>$\eta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>40–200 bars</td>
<td>90–400</td>
<td>0.15–0.8</td>
</tr>
</tbody>
</table>

Inversion results

<table>
<thead>
<tr>
<th>$\Delta \sigma$</th>
<th>$Q_o$</th>
<th>$\eta$</th>
</tr>
</thead>
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<tr>
<td>105.14 bars</td>
<td>92.41</td>
<td>0.21</td>
</tr>
</tbody>
</table>

**PGA attenuation relations**

**Strong ground motion data**

- 66 strong motion data (Mw≥4.5 and D≤30 km)
- 36 strong motion station (bedrock)

**Empirical relations**

- Yanxiang YU and Suyun WANG (Western China, 2006)
  \[ \log_{10}(PGA) = 2.296 M_w + 0.532 R + 1.041 \log_{10}(d + 2.832) \]
  \[ \log_{10}(PGA) = 1.019 M_w + 0.901 R - 1.441 \log_{10}(d + 0.340) \]

- Jincheng LEI, et al. (Sichuan basin, 2007)
  \[ \log_{10}(PGA) = -1.2324 + 1.5406 M_w - 0.4415 R - 1.2322 \log_{10}(d + 0.8091) \]
  \[ \log_{10}(PGA) = -2.1370 + 1.4893 M_w - 0.9312 R - 1.7246 \log_{10}(d + 0.4021) \]

- Jincheng LEI, et al. (southwestern region, 2007)
  \[ \log_{10}(PGA) = -0.3348 + 1.3807 M_w - 0.9660 R - 2.1928 \log_{10}(d + 2.3225) \]
  \[ \log_{10}(PGA) = -1.0238 + 1.6743 M_w - 0.8713 R - 1.8409 \log_{10}(d + 1.8417) \]

- Jianwen CUI, et al. (Yunnan, 2006)
  \[ \log_{10}(PGA) = 3.5549 + 0.2881 M_w + (2.7317 + 0.0889 R) \cdot \log_{10}(d + 13) \]

- Jianguang XIANG and Dong GAO (Yunnan, 1992)
  \[ M_w = 0.07213(R + 15)^{0.35} \]
\[
\text{residual} = \frac{1}{N} \sum_{i=1}^{N} \log\left( \frac{\text{observed value}}{\text{predicted value}} \right)
\]

<table>
<thead>
<tr>
<th>Relations</th>
<th>Mw = 5</th>
<th>Mw = 6</th>
<th>Mw = 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Xiang, et al. (1992)</td>
<td>-0.1524</td>
<td>-0.0895</td>
<td>0.1381</td>
</tr>
<tr>
<td>Cui, et al. (2006)</td>
<td>0.3242</td>
<td>0.1988</td>
<td>0.2376</td>
</tr>
<tr>
<td>Yu, et al. (2006)</td>
<td>-0.0697</td>
<td>-0.2282</td>
<td>-0.1191</td>
</tr>
<tr>
<td>Lei, et al. (2007)</td>
<td>0.1927</td>
<td>0.0306</td>
<td>0.0524</td>
</tr>
<tr>
<td>Lei, et al. (2007)</td>
<td>0.2543</td>
<td>-0.0437</td>
<td>0.1091</td>
</tr>
<tr>
<td></td>
<td>0.4792</td>
<td>0.1359</td>
<td>0.2106</td>
</tr>
<tr>
<td>Lei, et al. (2007)</td>
<td>0.2997</td>
<td>0.0083</td>
<td>0.1130</td>
</tr>
<tr>
<td></td>
<td>0.3395</td>
<td>0.0646</td>
<td>0.1222</td>
</tr>
<tr>
<td>This study</td>
<td>0.2092</td>
<td>0.1053</td>
<td>-0.1217</td>
</tr>
</tbody>
</table>

The end

Thanks