Seismology based strong ground motion attenuation relationship for national zoning map

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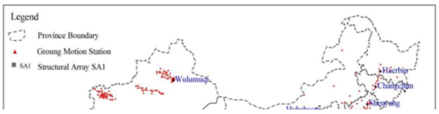
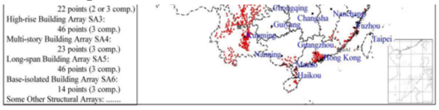
Background

- 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)

Background

- 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 $I_A(M_A, R_A)$ of region A and $I_B(M_B, R_B)$ of region B, so that they give the same intensity I and ground motion Y.

Region A:

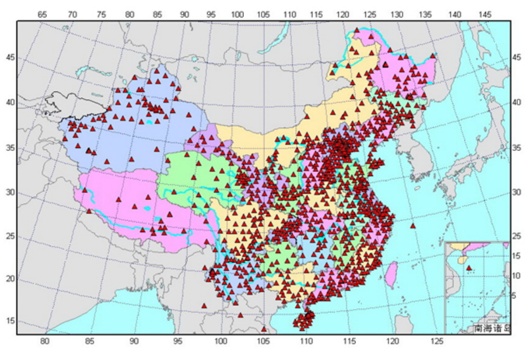
$$I_A = 0.514 + 1.500M_A - 0.00659R_A - 2.014\log(R_A + 10)$$

$$\log(Y_A) = 1.297 + 0.566M_A - 1\ 723\log[R_A + 1\ 046e^{0.5M_A}]$$

Region B:

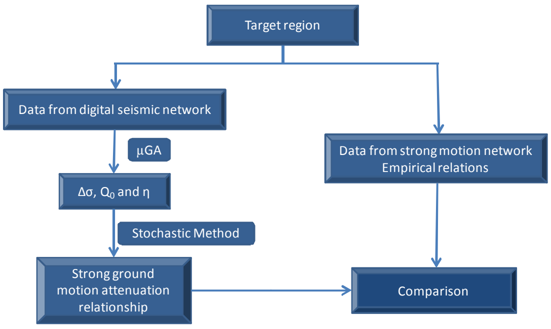
$$I_B = 5.019 + 1\ 446M_B - 4.136\lg(R_B + 24)$$

$$\log(Y_B) = 2.027 + 0.548M_B - 1.902\log[R_B + 1.700e^{0.425M_B}]$$



China Earthquake Data Center

Framework



Methodology

Assuming the accelerations, on the far-field and an elas ic half space, are band-limited, finite-duration, white Gaussian noise, and based on Brune ω^2 model, he source Fourier spectra $FA(M_0, f, R)$ on a site can be described as

$$FA(M_0, f, R) = C \cdot S(M_0, f) \cdot G(R) \cdot D(R, f) \cdot A(f) \cdot P(f) \cdot I(f)$$

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.

$$C = \frac{R_{\theta\phi} FV}{4\pi R_0 \rho_s \beta_s^3}$$

$$D(R, f) = \exp\left(-\frac{\pi f R}{Q\beta}\right)$$

$$S(M_0, f) = \frac{M_0}{1 + \left(\frac{f}{f_0}\right)^2}$$

$$Q = Q_0 f^{\eta}$$

$$f_0 = 4\ 9 \times 10^6 \beta (\Delta\sigma / M_0)^{1/3}$$

$$P(f) = \left[1 + \left(\frac{f}{f_{max}}\right)^8\right]^{-1/2}$$

$$G(R) = \begin{cases} \frac{1}{R} & R \le 70 \\ \frac{1}{70} & 70 < R < 130 \\ \frac{1}{70}\sqrt{\frac{130}{R}} & R \ge 130 \end{cases}$$

$$I(f) = (2\pi f)^z$$

Following Hanks (1979), we estimate the a_{rms} using Parseval's theorem. The estimation is valid for a time window equal to the faulting duration T_d beginning with the direct shear arrival; in Hanks (1979), $T_d = 1/f_o$. In terms of spectral parameters, Ω_0 and f_o, the result is

$$a_{ms} = \left(\frac{m_0}{T_d}\right)^{1/2}$$

$$m_0 = 2\int_{f_0}^{f_{max}} |FA(f)|^2 df \approx 2\int_{f_0}^{f_{max}} \left|\Omega_0 (2\pi f_0)^2 \times e^{-\frac{\pi f R}{Q\beta}}\right|^2 df$$

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

$$m_k = \int_{-\infty}^{\infty} (2\pi f)^k |FA(f)|^2 df$$

The peak factor γ_m, which describes the ratio of peak to rms motion, is calculated by the following numerical integration,

$$\gamma_m = 2\int_0^{\infty} \left\{1 - \left[1 - \xi \exp(-z^2)\right]^{N_e}\right\} dz$$

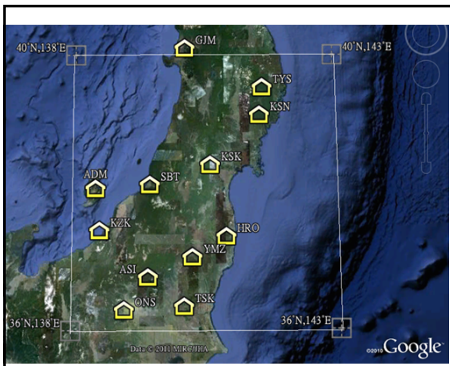
$$\xi = \frac{N_z}{N_e} = \frac{m_2}{(m_0 m_4)^{1/2}} \qquad N_{z,e} = 2 f_{z,e} T$$

$$f_z = \frac{1}{2\pi}(m_2/m_0)^{1/2}$$

$$f_e = \frac{1}{2\pi}(m_4/m_2)^{1/2}$$

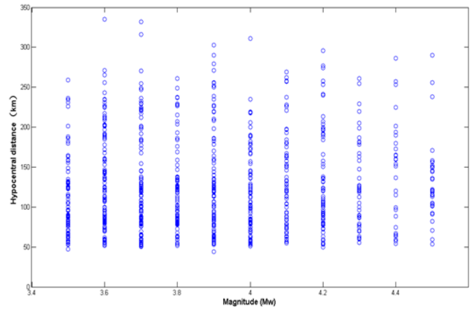
PGA= $\gamma_m * a_{rms}$

CASE OF SENDAI AREA

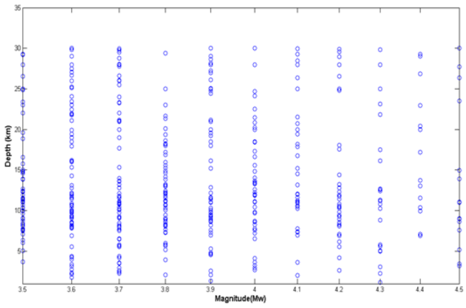


1996.1-2011.4

12 F-net stations
632 earthquakes



Distribution of hypocentral distance with Mw



Distribution of focal depth with Mw

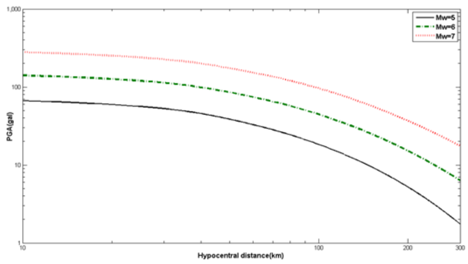
Inversion ranges

Δσ	Qo	η
40~100 bars	100~300	0.6~1

Inversion results

Δσ	Qo	η
45.17 bars	124.91	0.61

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 (T_G<0.2s)

Empirical relations

- Tatsuo Kanno, *et al*., (2006)

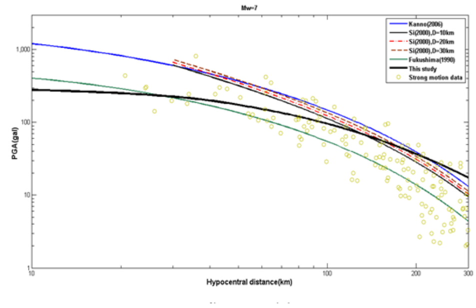
$$\log(PGA) = 0\ 56M_w - 0\ 003\ 1X - \log(X + 0\ 0055 \cdot 10^{0.5M_w}) + 0\ 26 + 0\ 37$$

- Hongjun Si, *et al*., (2000)

$$\log(PGA) = 0\ 58M_w + 0\ 0039D + 0\ 12 + 0\ 28 - \log X_{eq} - 0\ 003X_{eq}$$

- Yoshimitsu Fukushima, *et al*., (1990)

$$\log(PGA) = 0.41M_s - \log_{10}(R + 0.032 \cdot 10^{0.41M_s}) - 0.0034R + 1.30$$



$$residual = \frac{1}{N}\sum_{i=1}^{N}\log_{10}\left(\frac{observed \quad value}{predicted \quad value}\right)$$

PGA relations	Mw=5	Mw=6	Mw=7
Fukushima (1990)	-0 2970	-0.0613	0.0887
Kanno (2006)	-0.4168	-0.3503	-0.3591
Si(2000), D=10	-0 2003	-0.1698	-0.2407
Si(2000), D=20	-0 2393	-0.2088	-0.2797
Si(2000), D=30	-0 2783	-0.2478	-0.3187
This study	-0 5093	-0.3894	-0.2520

Case of Southwestern China

Sichuan Province

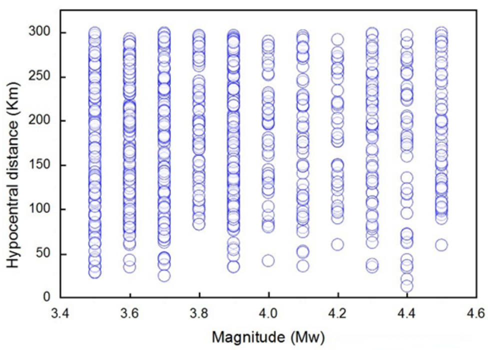
2001-2007

29 seismic stations
48 earthquakes
147 records

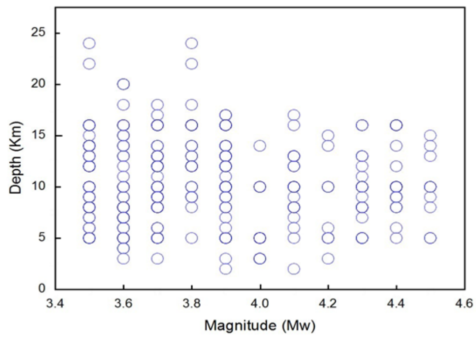
Yunnan Province

2001-2007

26 seismic stations
162 earthquakes
863 records



Distribution of hypocentral distance with Mw



Distribution of focal depth with Mw

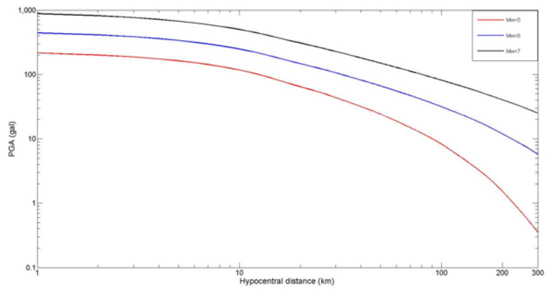
Inversion ranges (Ye, 2001; Su, 2009)

Δσ	Q_o	η
40~200 bars	90~400	0.15~0.8

Inversion results

Δσ	Q_o	η
105.14 bars	92.41	0.21

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)

$$\log_{0}(PGA) = 2.206 M_s + 0.532 M_s - 1.954 \log_{0}(R + 2.018 \quad e^{0.\ 06 M_s})$$
$$\log_{10}(PGA) = 1\ \ 010 M_s + 0.501 M_s - 1.441 \log_{0}(R + 0.340 \quad e^{0.521 M_s})$$

- Jiancheng LEI, et al. (Sichuan basin, 2007)

$$\log_{10}(PGA) = -1\ \ 8244 + 1.5408 M_s - 0.0845 M_s^2 - 1\ \ 6392 \quad \log_{0}(R + 0.8691 \quad e^{0.38 \quad M_s})$$
$$\log_{0}(PGA) = -2.1376 + 1.4860 M_s - 0.0812 M_s^2 - 1.3846 \quad \log_{10}(R + 0.4022 \quad e^{0.\ \ 56 M_s})$$

- Jiancheng LEI, et al. (southwestern region, 2007)

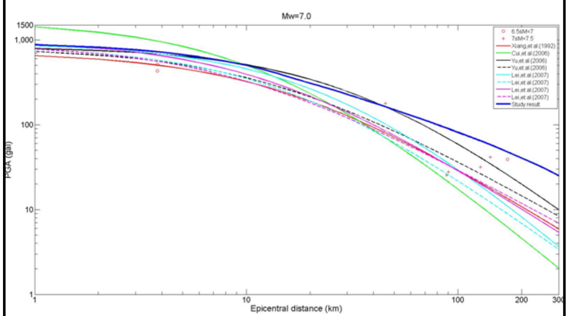
$$\log_{10}(PGA) = -0.3349 + 1\ \ 3807 M_s - 0.0665 M_s^2 - 2.1920 \quad \log_{0}(R + 2.5292 \quad e^{0.333 \quad M_s})$$
$$\log_{10}(PGA) = -1.5206 + 1.4539 M_s - 0.0715 M_s^2 - 1.8499 \quad \log_{0}(R + 1.0617 \quad e^{0.385 \quad M_s})$$

- Jianwen CUI, et a . (Yunnan 2006)

$$\log_{10}(PGA) = 3.5549 + 0.2881 M_s + (-2.7317 + 0.0889 M_s) \cdot \log_{10}(R + 13)$$

- Jianguang XIANG and Dong GAO (Yunnan, 1992)

$$PGA = 1291\ \ 07 e^{0.5275 M_s} (R + 15)^{-1.5785}$$



$$residual = \frac{1}{N}\sum_{i=1}^{N}\log_{10}\left(\frac{observed \quad value}{predicted \quad value}\right)$$

Relations	Mw =5	Mw =6	Mw =7
Xiang, et al. (1992)	-0.1524	-0 0895	0.1381
Cui, et al. (2006)	0 3242	0.1188	0 2376
Yu, et al. (2006)	-0 0907	-0 2262	-0.1191
	0.1957	0 0306	0 0524
Lei, et al. (2007)	0 2543	-0 0437	0.1091
	0.4792	0.1359	0 2108
Lei, et al. (2007)	0 2997	0 0083	0.1130
	0 3395	0 0646	0.1222
This study	**0.2092**	**0.1053**	**-0.1217**

The end

Thanks