A new ground motion prediction equation (attenuation relation) for Japan based on the 2011 Tohoku-oki earthquake records

Nobuyuki Morikawa and Hiroyuki Fujiwara
National Research Institute for Earth Science and Disaster Prevention (NIED), Japan
Background

- We have constructed a database of strong-motion records and have obtained a new attenuation relation. (Kanno et al., 2006; BSSA)

- The Tohoku-oki mega-earthquake (Mw=9.0) on March 11, 2011, is the largest event which many strong-motion records were obtained. (over 2,000 records in Japan)

- We must consider Mw9-class mega-earthquakes (e.g. Nankai trough earthquake) in our seismic hazard assessment.

A new attenuation relation directly applicable up to Mw=9 earthquakes is required for the “Next Generation National Seismic Hazard Maps for Japan”.

Strong-Motion Data during the M9 Earthquake vs Existing Japanese Attenuation Relations

- **Observed (on the ground)**
  - Si & Midorikawa (1999): for inter-plate earthquakes
  - Kataoka et al. (2006): for subduction-zone earthquakes
  - Kanno et al. (2006): for shallow (<30km) earthquakes
  - Satoh (2010): for inter-plate earthquakes (Pacific plate)

Assumed source fault based on HERP (2011)
Strong-Motion Data

- Update the strong-motion database of Kanno et al. (2006) by adding recent (after the 2003 Tokachi-oki EQ) records.
  - Up to end of 2009 and the 2011 Tohoku-oki main shock
  - NIED (K-NET and KiK-net), JMA, PARI

- Target strong-motion parameters:
  - JMA seismic intensity (I)
  - Peak ground acceleration (PGA)
  - Peak ground velocity (PGV)
  - 5% damped acceleration response spectra (SA; 0.05-10s)

- Data used in the regression analysis
  - Earthquake: $M_w \geq 5.5$ & number of records $\geq 5$
  - Station: $X \leq 200$ km & installed on the ground surface
    $X$: closest distance to the source fault
Modeling

- The main part follows to that in Kanno et al. (2006)
  - We use only two parameters, moment magnitude (Mw) and closest distance to source fault (X) in “base model”.
  - We apply “additional correction terms” in order to express other phenomena such as site amplification and so on.

- We obtain regression coefficients for individual earthquake category (subduction-zone earthquakes and shallow crustal earthquakes).

- We exclude the focal-depth dependency from the “base model”.
  - We think that the difference of attenuation term can be expressed by using the earthquake category instead of the focal depth.
Modeling of Magnitude Term

\[ \log A = \sum_{i} \alpha_i + b \cdot X - \log(X) \]

\( \alpha_i \) can be determined for each earthquake

"\( \alpha_i \)" saturates at Mw=8 or more
Modeling of Magnitude Term

Model-1

Amplitude saturation is approximated by using $M_w^2$ term (based on Fukushima, 1996)

Model-2

Amplitudes are completely saturated at $M_w \geq M_{w_0}$

※ This figure is based on Fukushima (1996)
Base Model

Model-1

\[ \log A = a_1^k (Mw - Mw_{01})^2 + b_1^k X - \log (X + d_1 10^{e_1 \cdot Mw}) + c_1^k \]

Model-2

\[ \log A = a_2^k Mw_{02} + b_2^k X - \log (X + d_2 \cdot 10^{e_2 Mw_{02}}) + c_2^k \]

\[ Mw_{02} = \min (Mw, Mw_0) \]

”k” is for subduction-zone or shallow crustal earthquakes

- \( Mw_0 \) & \( e \) are assumed to be independent of the period and earthquake category
- By trial and error approach, the following parameters fixed as

\[ Mw_{01} = 16.0, \ e_1 = 0.3, \quad Mw_{02} = 8.3, \ e_2 = 0.5 \]
Mw=9.0, Mw=8.0, Mw=7.0, solid: subduction, dashed: crustal, thin: Kanno et al. (2006)
Comparison of Base Model with Observed Data

Model-1

2003/09/26 04:50 Mw=7.9

Model-2

2003/09/26 04:50 Mw=7.9

2004/10/23 17:56 Mw=6.5

2004/10/23 17:56 Mw=6.5

2011/03/11 14:46 Mw=9.0

2011/03/11 14:46 Mw=9.0
In order to model amplification characteristics by deep sedimentary layers, we examine the relation between residual (=log [obs/pre]) and top depth of the layer with Vs=1 at observation site ($D_l$) obtained from the “underground structure model of deep sedimentary layers for whole Japan”.

- “pre” is calculated from “base model”.

- The structure model consists of 6 major layers on the seismic bedrock whose $Vs = 3100$ m/s or more.
  1$^{st}$ layer: $Vs = 600$ m/s (engineering bedrock)
  2$^{nd}$ layer: $Vs = 1100$ m/s
  3$^{rd}$ layer: $Vs = 1400$ m/s
  4$^{th}$ layer: $Vs = 1700$ m/s
  5$^{th}$ layer: $Vs = 2100$ m/s
  6$^{th}$ layer: $Vs = 2700$ m/s
Additional Correction Term-1
-Amplification by deep sedimentary layers-

We modeled as:

\[ G_{\text{deep}} \,(= \text{residual}) = \begin{cases} q_d_p_d \cdot \log(D_l / D_{l0}) + q_d \\ D_l \leq D_{l0} \\ D_l > D_{l0} \end{cases} \]

\[ D_l : \text{Top depth of the layer with } Vs=1 \text{ (m/s) at the site [in m]} \]
Additional Correction Term-1
-Amplification by deep sedimentary layers-

σ: Standard deviation
We modeled as;

\[ G_{\text{shallow}} (= \text{residual}) = \begin{cases} 
  p_s \cdot \log Vs30 + q_s & \text{Vs30} \leq Vs30_0 \\
  p_s \cdot \log Vs30_0 + q_s & \text{Vs30} > Vs30_0 
\end{cases} \]
Additional Correction Term-2

-Amplification by shallow soft soils-

σ: Standard deviation

- Before Correction
- After Correction
Conclusions

✔️ We suggest a new attenuation relation (ground motion prediction equation) for Japan directly applicable up to Mw=9 by using the strong-motion records of the 2011 Tohoku-oki mega-earthquake.

✔️ We examine two different base models to express amplitude saturation at large magnitude, but we cannot decide which model is better yet.

✔️ We also suggest additional terms corresponding to site amplification that can be correct not only shallow soft soils but also deep sedimentary layers.
Further Problems

✓ Our new model cannot be constrained at near source region for large earthquakes (\(X<40\text{km} & Mw>7\)) because there is no strong-motion records in this regression analysis.

✓ We should add many strong-motion records of aftershocks of the Tohoku-oki earthquakes.
Thank you for your attention!