Novel Approach to Strong Ground Motion Attenuation Modeling

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Observed main features of PGA

Spatial distribution of ground motion data from recent earthquakes unveiled some features of peak ground acceleration (PGA) attenuation with respect to closest distance to the fault ($R$) that current predictive models may not effectively capture:

– PGA remains constant in the near-fault area
– PGA may show an increase in amplitudes at distances of about 3-10 km from the fault-rupture
– PGA attenuates with slope of $1/R$ and faster at farther distances,
– PGA intensifies at certain distances due to basin effect (if basin is present).
Attenuation plots of G-functions with various $R_o$ and $D_o$

2004 Parkfield Earthquake
Mw = 6.0; Style of Faulting = Strike-Slip

Fault Distance (km)

PGA (g)

Eq. Data

- G-function: $R=5$, $D=0.3$
- G-function, $R=6$, $D=0.5$
- G-function, $R=6$, $D=0.3$
Transfer function of a SDOF oscillator:

\[ G(\lambda) = \frac{A}{\sqrt{(1 - \lambda^2)^2 + 4D_0^2 \lambda^2}} \]

According to this analogy, distance \( R \) replaces square of frequency

\[ G(R) = \frac{A}{\sqrt{(1 - \frac{R}{R_0})^2 + 4D_0^2 \frac{R}{R_0}}} \]

Physical meaning of \( R_0 \) – corner distance (proportional to magnitude).
Implementation of secondary filter to primary attenuation function (i.e., $G \times G_1$ function fit)

2004 Parkfield Earthquake
$M_w = 6.0$; Style of Faulting = Strike-Slip

![Graph showing PGA vs Fault Distance with different attenuation functions]
PGA ground motion attenuation model

\[ \ln(Y) = \ln[A(M, F)] - 0.5\ln\left(1 - \frac{R}{R_0}\right)^2 + 4D_0^2 \frac{R}{R_0} \] - 0.5\ln\left(1 - \frac{R}{R_1}\right)^2 + 4D_1^2 \frac{R}{R_1} + b_v \ln \frac{V_{530}}{V_A} + \sigma_{\ln Y} \]

where

\[ A(M, F) = [c_1 \arctan(M + c_2) + c_3] \cdot F \]

\[ R_0 = c_4 M + c_5 \]

\[ D_0 = c_6 \cos[c_7(M + c_8)] + c_9 \]

<table>
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<th>( c_1 )</th>
<th>( c_2 )</th>
<th>( c_3 )</th>
<th>( c_4 )</th>
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**Note (1):** To capture basin effect it is recommended to set \( D_1 = 0.35 \), otherwise \( D_1 = 0.65 \)

**Note (2):** \( F = 1.00 \) for strike-slip and normal faulting; \( F = 1.28 \) for reverse faulting

**Note (3):** \( R = \) Closest fault distance and \( M = \) Moment magnitude

Graizer-Kalkan (2007) ground motion attenuation model for PGA
D and R scaling with magnitude

Magnitude-scaling for strike-slip earthquakes
Dislocation modeling (Bykovtsev et al., 1990) demonstrated similar effect: maximum motion observed at some distance from the fault for M~6.0.
Shear-wave velocity site correction

\[ F_{site} = b_v \cdot \ln\left(\frac{V_{S30}}{V_A}\right) \]

Boore et al., 1997

In the linear site amplification formula of Boore et al. (1997) \( b_v = -0.371 \). Our estimates yield \( b_v = -0.24 \) (similar to Field (2000)). Our model exhibits less amplification as the \( V_{S30} \) decreases compared to stiff site conditions.
Earthquake data distribution with respect to Mw (left) and PGA (right)

- Total of 2,583 data points from 47 shallow crustal earthquakes with depths less than 20 km were utilized. We used NGA database with a number of additions including Parkfield and San Simeon earthquakes.
Basin effect

Peak Ground Acceleration vs Fault Distance
Mw 6.5, VS\textsubscript{30} = 360 m/s, Strike-Slip Fault

Fault Distance (km)

PGA (g)

- **Basin Effect**
- **No Basin Effect**
Comparison of recorded data with model predictions

- **2004 Parkfield Earthquake**
  - $M_w = 6.0$; Style of Faulting = Strike-Slip
  - Graph showing PGA vs. Fault Distance (km)

- **1979 Imperial Valley Earthquake**
  - $M_w = 6.5$; Style of Faulting = Strike-Slip
  - Graph showing PGA vs. Fault Distance (km)

- **1994 Northridge Earthquake**
  - $M_w = 6.7$; Style of Faulting = Reverse
  - Graph showing PGA vs. Fault Distance (km)

- **1999 Chi-Chi (Taiwan) Earthquake**
  - $M_w = 7.6$; Style of Faulting = Reverse
  - Graph showing PGA vs. Fault Distance (km)
Comparison with Global Shakemap Dataset
Shift of predominant period of average spectral shape with increase in magnitude and distance
Modeling Spectral Acceleration (SA)

In order to find a continuous function for SA prediction, the sum of two functions was used:

- Log-normal distribution function
- SDOF transfer function (smoothed Heaviside)
Approximation function fit to average spectral shape of 1999 M7.6 Chi-Chi earthquake
Continuous function of Spectral Acceleration

\[ SA(T) = \text{PGA} \times \left[ F1(T) + F2(T) \right] \]

where

\[ F1(T) = \text{Modified Log Normal Distribution} \]
\[ F2(T) = \text{Modified SDOF Transfer Function} \]

\[ SA_{\text{norm}}(T/M, R, V_{S30}) = I(M, R) e^{-\frac{1}{2} \left( \frac{\ln(T) + \mu(M, R, V_{S30})}{S(M, R)} \right)^2} + \frac{1}{\sqrt{\left( 1 - \left( \frac{T}{T_{sp,0}} \right)^\zeta \right)^2 + 4D_{sp}^2 \left( \frac{T}{T_{sp,0}} \right)^\zeta}} \]

\[ R = \text{Closest fault distance} \]
\[ M = \text{Moment magnitude} \]

Diagram: Generic model for response spectrum.
Prediction of SA ordinates based on integration of GK07 PGA attenuation relation with GK08 spectral shape predictive model
CLOSING REMARKS

• New approach to modeling peak ground motion attenuations is developed (Graizer & Kalkan, Earthquake Spectra, 2007).

• New approach to modeling response spectra as a continuous function is developed (Graizer & Kalkan, Earthquake Spectra, accepted).