NGAW1 – NGAW2 Comparison and Other Considerations for Ground Motions for Dams

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USSD, Apr 10, 2014

Comparison plots prepared by Nick Gregor
Median: SS, PGA, VS30=760
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Median: SS, T=1, VS30=760
Median: SS, $T=1$, $VS30=760$
Median: M7, REV, PGA, VS30=760
Median: M7, REV, T=1, VS30=760
Figure 6: Comparison of FW and HW effects on PGA for a 45 degree, M6.7 earthquakes for VS30 = 760 m/sec for both surface rupture (left frame) and buried rupture (right frame) with a top of rupture of 6 km.
Median: SS, 10 km, 760

Mag = 5, Rx = 10km

Mag = 6, Rx = 10km
Median: SS, 10 km, 760
SS, VS30=450

Mag = 5, Rx = 10km

Mag = 6, Rx = 10km
SS, R=10 km, VS30=450

Figure 2: Spectra-Case01: SS, Dip 90, Vs450m/s, Rx=10km
Spectral Displacements (SS, 10 km)
Spectral Displacements (SS, 10 km)

Mag = 7, Rx = 10km

Mag = 8, Rx = 10km

PSD (cm)

Period (sec)

ASK-W2
BSSA-W2
CB-W2
CY-W2
IM-W2
AS08
BA08
CB08
CY08
IM08
Figure 3: Comparison of magnitude scaling of the median ground motion for vertical strike-slip earthquakes at a distance of $R_{rup} = 30$ km for $VS30 = 760$ m/sec.
Mag Scaling, SS, R=30, VS=760
Sigma Models (M7, M8)

Mag = 7, Rx = 10km

Mag = 8, Rx = 10km
Sigma Models (M5, M6)

Mag = 5, Rx = 10km

Mag = 6, Rx = 10km
Other Considerations

• Simulations
• Kappa (Hard-rock sites)
Finite-Fault Simulations

• SCEC Broad-band platform (BBP)
  – Kinematic models
• Validation Project (see SCEC for details)
  – Validation part A
    • Compare simulations with past earthquakes
    • 7 events used
  – Validation Part B
    • Check the forward FFS against GMPE for M,R that is well constrained by data (M6-M6.6, R20-50)
Finite Fault Simulations

• Three methods passed the validation
  – Graves and Pitarka
  – SDSU (Olsen)
  – EXSIM (Atkinson)
Short Distance Scaling M7.2

[Graph showing PSA (g) vs Rupture Distance (km) with various datasets and symbols for different models and time periods.]
Short Distance Scaling M7.2
Example of HW effects from Simulations and NGA-W2 models
Issue for hard-rock sites

• GMPEs are poorly constrained for hard-rock conditions
  – Few data for VS30 > 1000 m/s

• Need to extrapolate models from soft-rock (well constrained) to hard-rock

• VS30 is not adequate to capture the high frequency site effects on rock sites
  – Kappa is best candidate for an additional site term
What is Kappa?

\[ \exp(-\pi \kappa f) \]

• **Kappa**
  – Accounts for attenuation of the high-frequency (related to material damping in the shallow crustal rock)
  – In practice, accounts for high-frequency differences between point source model and observations
    • May be done to source effects, as well as site effects
  – Main effect is at short distances
    • Q (damping in the deep crust) dominates kappa for large distances
$\omega^2$ Source Model: Effect of Kappa

Acceleration Fourier Amplitude Spectrum (cm/s)

- Kappa = 0.006 sec
- Kappa = 0.02 sec
- Kappa = 0.04 sec
- Kappa = 0.06 sec

Frequency (Hz)
Kappa and VS30
(From VanHoutte et al, 2010)

Figure 10: $\kappa_0$-$V_{S30}$ data from various papers (see legend) and from the present study (left). The same data are plotted together with the correlations from Silva et al. (1998), Chandler et al. (2006) and from the present study (right).
What we would expect from a pure kappa correction
Example Effect of VS-Kappa Correction on Response Spectra
Kappa and GMPEs

- GMPEs scale with VS30
  - Shouldn’t kappa effects be captured in the VS30 scaling?
  - Not in GMPEs
20 Hz Residuals from ASK14

[Graph showing residuals vs. VS30 (m/s)]
Correcting GMES for VS-kappa

• Develop for a well constrained reference VS30 (e.g. 760 m/s)
• Estimate kappa for each GMPE (for reference VS30)
• Develop VS -for each GMPE
• For site-specific application
  – find contribution of GMPEs to hazard (at 10 Hz)
  – Interpolate VS-kappa corrections to the site-specific values
  – Compute weighted average of VS-kappa scale factors for each GMPE
  – Apply average scale factor to the UHS
    • Gives same result as correcting the UHS if linear site response
Adjusting GMPEs for Kappa

- Hybrid empirical method (HEM)
- Inverse RVT method (IRVT)
- Empirical (residuals) method
IRVT-Based Approach

- Compute GMPE response spectra for host region at short distances on stiff soil or rock
- Use IRVT (strata program, Kottke & Rathje 2008) to invert the GMPE response spectra to FAS
- Estimate the host $\kappa_0$ from the FAS based on the slope in the high frequency spectra
- If target $\kappa < \kappa_0$, define a new host FAS with the high frequency modified based on $\kappa_0$ scaling, (Anderson & Hough, 1984)
IRVT-Based Approach (cont’d)

- Apply kappa scaling by multiplying host FAS by
  \[ \exp( -\pi (\kappa - \kappa_0) f ) \]
- Apply Vs scaling by multiplying the kappa-scaled FAS by the ratio of target to host amplification functions
- Convert the kappa and Vs-kappa scaled FAS to response spectra using RVT
- Compute the kappa and Vs-kappa scaling factors as the ratio of scaled Sa values to GMPE Sa values
Example Application Using IRVT

• Host GMPE:
  – Campbell & Bozorgnia (2008), CB08
    • WUS generic rock profile with Vs30 of 620 m/sec
    • Average host kappa based on the high frequency slope of IRVT-based FAS

• Target region: Switzerland
  • Generic Swiss rock conditions with Vs30 of 1000 m/sec
  • Average target kappa based on the high frequency slope of IRVT-based FAS (kappa₀ = 0.017)
Vs-Kappa Scaling of CB08

Average host kappa = 0.041 sec, stdev = 0.0015

Average target kappa = 0.022 sec (kappa₀ = 0.017), stdev = 0.0019
Vs-Kappa Scaling of CB08 (cont’d)

M6 - Rjb 10km - Vs 620m/sec

M6 - Rjb 10km – Vs 1000m/sec
Scaling Factors for CB08
Measuring Kappa

• Kappa needs to be measured at a site from earthquakes
  – Kappa cannot be measured in lab
  – Possible that Kappa can be estimated using ambient noise, but needs work

• Need free-field seismic instrument at site
  – Ideal data is small magnitude (M2) at short distances (< 50 km)
  – Can use smaller magnitudes and larger distances, but greater uncertainty in kappa due to trade-off with Q
  – May take years to get a good recording
Summary: Issues for NGA-W2 Models

• Changes from NGA-W1
  – Small changes for large magnitudes at short distances
  – Large changes at large distances, moderate magnitudes M<6
  – Regionalization

• Depth Scaling
  – Strong depth (ZTOR or hypo depth) scaling for three models (ASK, CB, CY)
    • Style-of-faulting is correlated with depth
    • Including depth reduces style-of-faulting factor for REV
  – No depth scaling in BSSA and Idriss models

• Normal faulting factors
  – Not well constrained in NGA-west2 models
Summary: Issues for NGA-W2 Models

• HW Scaling
  – Strong effect in ASK, CB, CY models
  – Few empirical data available
  – Scaling constrained by simulations
    • HW models are questionable for dips less than 25 degrees
  – Implicit HW in BSSA through RJB distance metric
  – Not included in Idriss model
Summary: Issues for NGA-W2 Models

• Finite-Fault Simulations
  – Three validated methods show wider range of GM than the NGA-W2 GMPEs
  – At short distances (<10 km), average scaling from FFS is consistent with NGA-W2 models
Summary: Issues for NGA-W2 Models

• Hard Rock
  – NGA-W2 models do not capture high freq content for low kappa hard-rock sites
  – Methods available to correct for kappa, but large uncertainty in estimation of kappa
Calculation of $m_0$

1) For low $f_{osc}$, (below the peak of $m_0$ but above $f_c$), $m_0$ is dominated by the Fourier spectrum at $f_{osc}$.

2) In the $f_{osc}$ range directly above the peak of $m_0$, the influence of the low frequency range of the Fourier spectrum increases and takes over for high oscillator frequencies $f_{osc}$.

3) For high $f_{osc}$, $m_0$ seems to be dominated by the Fourier spectrum between the source corner $f_c$ (0.2 Hz) and kappa and Q generated corner frequencies.
HEM

• Estimate the (host) point-source model parameters that fits the GMPE
• Estimate the (target) point-source model parameters
• Compute $Sa$ using point source models for host and target regions
  – Compute ratio of $Sa$ for given $M, R$
  – Apply the $Sa$ ratio to the host GMPE
Potential Strengths of RVT-Based Approach

• Simple and transparent

• Applies scaling in Fourier domain as opposed to response spectra domain

• Does not require a full seismological model for stochastic parameters of host and target regions

• Does not assume that response spectral shape of GMPE is consistent with that of the point source stochastic model
Potential Weaknesses of RVT-Based Approach

- Relies on IRVT to produce response spectra-compatible FAS
  - Stationary process over the duration
  - Curling of the high frequency FAS for GMPEs where Sa has positive slope at high frequency (ex Zhao et al. 2006)

- Requires that Anderson & Hough (1984) kappa scaling fits reasonably well the high frequency FAS

- Modifying the high frequency FAS to follow kappa scaling introduces misfit between the initial and calculated response spectra
Empirical Approach

• Evaluate the dependence of residuals on kappa
  – Traditional approach to new terms

• Difficulty
  – Need estimate of kappa for each recording in the data base
  – Kappa is often not uniquely determined from slope of FAS
Empirical Approach

• Measure the high frequency shape of the spectrum
  – Define term: famp1.5
Empirical Approach

- Derive kappa-famp1.5 relationships using IRVT-scaled response spectra to different target kappa values.
Empirical Approach

- Evaluate within-event residuals of empirical ground motion data from the host region with respect to host region GMPE
- Calculate famp1.5 and estimated kappa for each recording
- Using within-event residuals of ground motion data at short distance (up to 50 km) and recorded on stiff soil (Vs30 > 600 m/sec), calculate average residuals for different kappa bins
Vs-Kappa Scaling of WUS Data – CB08

\[ k \text{ Scaling Factor (T 0.05 sec)} = \exp(-0.492 \ln(k) - 1.368) \]
Initial GMPE
RVT-Based Approach
Swiss
Hybrid Emp, Host $k = 0.04$, Target $k = 0.017$
Hybrid Emp, Host $k = 0.035$, Target $k = 0.017$
Hybrid Emp, Host $k = 0.048$, Target $k = 0.017$
Empirical Approach, Target $k = 0.017$
Summary of GMPE adjustments

• For large changes in kappa (e.g. 0.04s to 0.01s)
  – HEM leads to the largest kappa scale factors
    • Overestimating correction due to inconsistencies in the spectral shape of the GMPE and the spectral shape of the point source model
  – IRVT leads to kappa scale factors between HEM and empirical
    • IRVT is unstable in high frequencies for which there is little energy in ground motion
  – Empirical tends to leads to smallest kappa scale factors
    • Sparse data at low kappa values to constrain scaling
    • Famp1.5 is not a direct estimate of kappa
Estimating Kappa for a Site

• Measurement of kappa from ground motion data at site
  – Preferred method

• Estimate kappa based on correlation with VS30
Kappa and VS30
(From VanHoutte et al, 2010)

Figure 10: $\kappa_0$-$V_{S30}$ data from various papers (see legend) and from the present study (left). The same data are plotted together with the correlations from Silva et al. (1998), Chandler et al. (2006) and from the present study (right).