Calibration of Hybrid Simulation Methodology

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Outline

• Hybrid simulation procedure
• Problems with existing procedure
  – Distance attenuation
  – Standard deviation
• Planned scope
  – Distance attenuation calibration
  – Intra-event scatter calibration
  – Verification
Motivation

- Broadband motions for response history analysis
- Some (M, R) ranges poorly sampled by recordings
Motivation

- Broadband motions for response history analysis
- Some (M, R) ranges poorly sampled by recordings
- Motions needed with specific attributes, e.g.
  - Basin effect
  - Near fault effects

Simulations hold potential to provide useful ground motions for engineering application in these situations

- Near fault effects
Simulation Procedure

• Hybrid procedure
  – f<1 Hz: physics based
Simulation Procedure

• Hybrid procedure
  – f<1 Hz: physics based
  – f>1 Hz: stochastic
Simulation Procedure

• Hybrid procedure
  – f<1 Hz: physics based
  – f>1 Hz: stochastic
Simulation Procedure

- Hybrid procedure
- Source function
  - Slip distribution
  - Rupture velocity

Shakeout, $M_w$ 7.8
Shake Out Simulations

- Hybrid procedure
- Source function
- Finite difference calculation
  - SCEC 3D velocity model
Shake Out Simulations

- Hybrid procedure
- Source function
- Finite difference calculation
- Semi-empirical site term (fn of $V_{s30}$)
Data Analysis

Approach:

• Calculate residuals

\[ R_i(T) = \ln \left( S_a(T) \right)_{\text{sim},i} - \ln \left( S_a(T) \right)_{\text{GMPE},i} \]

• 4 NGA GMPEs: AS, BA, CB, CY

• Random effect analysis: Separate event term \((\eta_i)\) from within-event residual \((\varepsilon_{i,j})\)

\[ R_{i,j} = \eta_i + \varepsilon_{i,j} \]
Use $\varepsilon_{ij}$ to evaluate $\sigma$, distance attenuation, directivity, and site effects.
Data Analysis

Approach:

- Calculate residuals
- 4 NGA GMPEs: AS, BA, CB, CY
- Random effect analysis: Separate event term ($\eta_i$) from within-event residual ($\varepsilon_{i,j}$)
- Gross assessment of source from $\eta_i$
- Distance-scaling evaluated from $\varepsilon_{i,j}$
Results: Event Terms

Result: Simulated motions consistent with GMPEs for $T < 1\ s$, exceed GMPEs for $T > 1\ s$
Results: Distance-Scaling

Result: Faster attenuation except at long periods.
Removing R-Scaling Bias

Procedure:

• Regress distance-scaling parameters in NGA equations

• Retain original functional form.

\[ F_{DIST} = \left[ c_4 + c_5 M \right] \times \ln \left( \sqrt{r_i^2 + h^2} \right) \]
Modified Coefficients

With 95% CI

Distance Term, $c_4$

Constant Term, $c_0$

Period (s)

Faster attenuation

CB Coefficients
- Original Value
- Modified Value

PGA
PGV
Modified GMPEs

- PGA Original
- PGA Modified
- $S_a(T=1.0s)$ Original
- $S_a(T=1.0s)$ Modified
- $S_a(T=10.0s)$ Original
- $S_a(T=10.0s)$ Modified

Strike-slip EQ $V_{s30}=540$ m/s

$R_{rup}$, $R_{jb}$ (km)

Acceleration (g)
Standard Deviation

\[ \sigma = \text{stdev}(\varepsilon) \]

Large transition at \( T = 1.0 \) s

\( \sigma \) too low for \( T < 1.0 \) s
Scope

- Distance attenuation calibration
  - Strike slip fault, M 5, 6.5, 8
  - Distributed and dense arrays
Scope

• Distance attenuation calibration
  – Strike slip fault, M 5, 6.5, 8
  – Distributed and dense arrays
  – Repeat Hybrid sim. for various levels of crustal damping
  – Identify parameters that remove bias
Scope

- Distance attenuation calibration
- Intra-event scatter calibration
  - Stochastic component of model
  - Fourier Amp.
  - Randomized
  - Randomization of $Q$
  - Various ways of specifying phase
Scope

- Distance attenuation calibration
- Intra-event scatter calibration
  - Evaluate effects of modifications on
    - Sigma
Scope

- Distance attenuation calibration
- Intra-event scatter calibration
  - Evaluate effects of modifications on
    - Sigma
    - Coherency within dense array

![Graph showing lagged coherency with frequency and distance]

- Lagged Coherency, $|\gamma|$
- Frequency (Hz)
- $|\gamma| = 10$ m, $|\gamma| = 100$ m
Scope

- Distance attenuation calibration
- Intra-event scatter calibration
- Verification